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Volume 1:
Urban Stormwater Characteristics, Sources and Pollutant Management by Street Sweeping

Wisconsin Department of Natural Resources
Madison, Wisconsin
1983

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EVALUATION OF URBAN NONPOINT SOURCE POLLUTION MANAGEMENT IN MILWAUKEE COUNTY, WISCONSIN

VOLUME I

URBAN STORMWATER CHARACTERISTICS, POLLUTANT SOURCES AND MANAGEMENT BY STREET SWEEPING

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PREFACE

This final report is submitted by Wisconsin Department of Natural Resources (WDNR) to the Environmental Protection Agency in partial fulfillment of a grant entitled Evaluation of Urban Nonpoint Pollution Management in Milwaukee, Wisconsin (Grant No. P005432-01-5). This project provided an evaluation of the characteristics, impacts, sources and management of urban stormwater pollution in Milwaukee. This was a four year intensive study, continuing from July 1979 until June 1983. The U. S. Geological Survey (USGS) and the Southeastern Wisconsin Regional Planning Commission (SEWRPC), under subcontract to the WDNR, have contributed extensively to this project.

DISCLAIMER

This report has been reviewed by the Urban Nonpoint Sources Section, U.S. Environmental Protection Agency, Washington, D.C. The report does not necessarily reflect the views and policies of the agency, and no official endorsement should be inferred. Mention of trade names of commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

This final report contains the findings, conclusions and recommendations of a study of the characteristics, sources and management of urban stormwater pollution in Milwaukee, Wisconsin. the study was conducted by the Wisconsin Department of Natural Resources, with major subcontracts to the U.S. Geological Survey and the Southeastern Wisconsin Regional Planning Commission. It was funded by the U.S. Environmental Protection Agency (Grant No. P005432-01-5) as part of the Nation-wide Urban Runoff Program. The study ran from July 1979 until June 1983.

This report is comprised of three volumes. Volume I contains the technical findings, conclusions and recommendations related to urban stormwater quantity, quality, impacts, pollutant sources and management. Volume II contains a economic evaluation of street sweeping and storage basins, plus three examples demonstrating the application of the conclusions and recommendations of this project to areawide water quality planning. Volume III contains the Materials and Methods, Quality Assurance, raw data, and other supportive and ancillary material related to this project.

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VOLUME I
CONTENTS

Page

Title Page.......... i
Preface.......... ii
Disclaimer.......... iii
Abstract.......... iv
Acknowledgments.......... v
Contents.......... vi
Tables.......... x
Figures.......... xiv

CHAPTER I. INTRODUCTION.......... I-1

CHAPTER II. CONCLUSIONS AND RECOMMENDATIONS.......... II-1

CHARACTERISTICS OF URBAN STORMWATER.......... II-1

IMPACTS OF URBAN STORMWATER.......... II-1

SOURCES OF URBAN STORMWATER CONTAMINANTS.......... II-2

MANAGEMENT ALTERNATIVES FOR URBAN STORMWATER.......... II-3

CHAPTER III. RUNOFF VOLUMES AND RAINFALL.......... III-1

INTRODUCTION.......... III-1

RAINFALL AND RUNOFF VOLUMES.......... III-1
Rainfall Volumes.......... III-2
Runoff Volumes.......... III-3
Duration of Runoff.......... III-3
Runoff Coefficients.......... III-4

COMPARISON OF THE OBSERVED RAINFALL AND RUNOFF TO ANNUAL AND AVERAGE VALUES.......... III-5
Regression Equations.......... III-6
Annual and Long-Term Average Rainfall.......... III-7
Predicted Runoff Versus Observed Runoff.......... III-7

SOURCES OF RUNOFF.......... III-10
Type of Analysis.......... III-10
Use of Data.......... III-10

USGS DISTRIBUTED ROUTING RAINFALL-RUNOFF MODEL.......... III-19
Description of the Model.......... III-19
Data Inputs.......... III-19
Calibration of the Model.......... III-21
Verification of the Model.......... III-21
Use of the USGS Distributed Routing Rainfall-Runoff Model.......... III-22

SUMMARY AND CONCLUSIONS.......... III-22

Page

CHAPTER IV. CHARACTERIZATION OF URBAN STORMWATER

CHAPTER IV. CHARACTERIZATION OF URBAN STORMWATER........................ IV-1

INTRODUCTION... IV-1

DESCRIPTION OF THE STORMWATER MONITORING PROGRAM........................ IV-2

CHARACTERISTICS OF MEAN EVENT CONCENTRATIONS............................ IV-3
  Average Concentration by Land Use.................................. IV-20
  Results of Multi-Element Scan Analyses............................. IV-20
  Comparison with EPA Criteria....................................... IV-22
  Particle Size Analysis... IV-26
  Long-Term BOD Concentrations....................................... IV-26
  Fecal Bacteria Samples... IV-29
  Seasonal Differences in Event Mean Concentrations.................. IV-31
  Water Quality Differences Between Paired Stations.................. IV-31

FLOW WEIGHTED AVERAGE CONCENTRATIONS.................................. IV-31
  Flow Weighted Average Concentrations for Urban and Agricultural Drainage Areas.................................... IV-33

ANNUAL LOADING VALUES... IV-38
  Normalized Unit Area Loading Values for Major Urban Land Uses....... IV-41
  Extrapolation of Unit Area Loading Values.......................... IV-42
  Annual Pollutant Loading Values in Urban and Agricultural Drainage Areas... IV-47
  Comparison of Stormwater and Treated Sanitary Wastewater............ IV-49

IMPACT ON RECEIVING WATERS.. IV-52

SUMMARY AND CONCLUSIONS... IV-56

Page

CHAPTER V. SOURCES OF URBAN STORMWATER.................................... V-1

INTRODUCTION.. V-1

STREET SURFACE CONTAMINANTS.................................. V-2
  Particle Size Distribution and Concentrations of Street Surface Contaminants.. V-2
  Variations in Street Loads Between Sites.......................... V-5
  Seasonal Variations in Street Surface Contaminant Loadings.......... V-15
  Accumulation Rates of Street Surface Contamination.................. V-28
  Rainfall Washoff of Street Surface Contaminants..................... V-35
  Contribution of Street Washoff to Total Runoff...................... V-37

ATMOSPHERIC CONTAMINANT DEPOSITION................................ V-45
  Atmospheric Deposition Monitoring................................ V-46

ATMOSPHERIC DRY DEPOSITION.. V-46
  Characterization of Dry Deposition............................... V-47
  Dry Deposition Rate Computation................................. V-49
  Deposition Rates Under Strong Wind Conditions.................... V-49
  Seasonal Variation in Deposition Rates........................... V-49
  Variations in Deposition Rates Amongst Sites..................... V-49

ATMOSPHERIC WET DEPOSITION.. V-52
  Variations in Concentrations Between Sites....................... V-52
  Comparison of Rainfall and Snowfall Quality...................... V-52
  Seasonal Variations in Precipitation Concentrations.............. V-52
  Comparison of Wet and Dry Deposition............................. V-55
  Trace Metals in Rain Water....................................... V-55
  Comparison of Concentration Data with Other Monitoring Programs..... V-55
  Contaminant Concentrations, Precipitation Volume and Proceeding Dry Interval.. V-57
  Precipitation Contaminant Contribution to Runoff Quality........... V-57

ROOFTOP RUNOFF QUALITY.. V-59
  Rooftop Runoff Monitoring.. V-59
  Variations in Rooftop Runoff Contaminant Concentrations Among Sites. V-60
  Comparision of Rooftop and Atmospheric Depositions................ V-60
  Sources of Zinc in Rooftop Runoff................................ V-64
  Contribution of Rooftop Runoff to Stormwater Contaminant Concentrations.. V-64
  Rooftop Runoff Contaminant Loading to Stormwater.................. V-64
  Rooftop Runoff Management.. V-69

SUMMARY AND CONCLUSIONS... V-69

Page

CHAPTER VI. IMPACTS OF STREET SWEEPING ON URBAN STORMWATER QUALITY..... VI-1

INTRODUCTION.. VI-1

STREET SWEEPER REMOVAL OF STREET SURFACE CONTAMINANTS................. VI-1

MONITORING THE WATER QUALITY IMPACTS OF STREET SWEEPING.............. VI-8

MODELING THE WATER QUALITY IMPACTS OF STREET SWEEPING................ VI-18

SUMMARY AND CONCLUSIONS.. VI-25

REFERENCES.. R-1

TABLES

Number Page

Chapter III

III.1 Rainfall for Sampled Events.................................. III-2
III.2 Runoff for Sampled Events.................................... III-3
III.3 Storm Duration for Sampled Events............................ III-4
III.4 Runoff Coefficient for Sampled Events........................ III-5
III.5 Regression Equations for Predicting Runoff Volume........... III-6
III.6 Observed and Predicted Runoff for All Sites................. III-8
III.7 Ratio of Observed to Predicted Runoff for All Sites......... III-9
III.8 DR3M Model Verification Results............................. III-23

Chapter IV

IV.1 Geometric Mean Concentration by Land Use.................... IV-21
IV.2 Event Mean Concentrations, mg/l, of Calcium, Iron, Manganese Exceeded by 10% and 50% of Events.......................... IV-23
IV.3 Event Mean Concentrations, mg/l, of Cadmium, Copper and Vanadium Exceeded by 10% and 50% of Events................ IV-24
IV.4 Percentage of Events with Event Mean Concentrations of Total Cadmium, Copper, Lead and Zinc Exceeding EPA Proposed Acute Toxicity Criteria for Dissolved Metals..... IV-25
IV.5 Concentrations of Total P, Volatile Solids and Total Lead in Suspended Solids by Particle Size................. IV-27
IV.6 Medians, Maximum and Minimum of the Event Mean Concentrations, mg/l, for 5-Day BOD, 30 Day BOD and Ultimate BOD.......... IV-28
IV.7 Summary of Fecal Bacteria Samples........................... IV-29
IV.8 Geometric Mean Seasonal Concentrations of Pollutants By Land Use.. IV-32
IV.9 Flow Weighted Average Concentrations, mg/l, of Solids, Metals and Chlorides... IV-34
IV.10 Flow Weighted Average Concentrations, mg/l, of Nutrients, 5-Day BOD and COD.. IV-35
IV.11 Flow Weighted Average Event Concentrations, mg/l, of Pollutants in Stormwater from the Study Areas, Urban Drainage Areas Adjacent to Study Areas and Selected Wisconsin Agricultural Drainage Areas.................... IV-37
IV.12 Average Annual Event Unit Area Loading Values for Water, m^3/ha, and for Solids, Metals and Chloride, kg/ha....... IV-39
IV.13 Average Annual Event Unit Area Loading Values for Water, m^3/ha, and for Nutrients, 5-Day BOD and COD, kg/ha...... IV-40

Page

IV.14 Normalized Annual Event Unit Area Pollutant Loading Values, kg/ha, for Established Urban Land Uses Monitored in Milwaukee County, Wisconsin.............................. IV-43

IV.15 Estimated Annual Event Pollutant Loading Values for Established Urban Land Uses Based on Unit Area Loading Values.. IV-46

IV.16 Normalized Annual Event Unit Area Pollutant, kg/ha, and Water, m^3/ha, Loading Values for the Study Areas, Urban Drainage Areas Adjacent to the Study Areas and Selected Wisconsin Agricultural Drainage Areas........................ IV-48

IV.17 Comparison of Annual Suspended Solids, Total Phosphorus and 5-Day BOD Loading Values, kg, in Study Areas Treated Sanitary Wastewater and Urban Stormwater.................. IV-51

IV.18 Annual Event Flow Weighted Average Concentrations, mg/l, Bottom Sediment Concentrations of Lead, ug/kg, and Biotic Index Values in the Menomonee River........................ IV-55

Chapter V

Page

V.1 Street Surface Sampling Summary.................................. V-3
V.2 Street Surface Texture Comparison................................ V-16
V.3 Mean Seasonal Loadings of Street Surface Contaminants......... V-17
V.4 Street Surface Contaminant Accumulation Rates, by Particle Size V-30
V.5 Street Surface Contaminant Accumulation Rates vs. Atmospheric Dry Deposition Rates.. V-32
V.6 Street Surface Contaminant Accumulation Rates Under Calm and Windy Conditions... V-33
V.7 Monitored vs. Calibrated Accumulation Rates.................. V-34
V.8 Average Change, %, of Street Surface Contaminant Loadings Following Rainfall.. V-36
V.9 Rainfall-Washoff Comparison at Congress and Hastings.......... V-39
V.10 Event and Street Loads for Three Probabilities at State Fair and Hastings, May-September................................ V-44
V.11 Composition of Total Solids in Dry Deposition................ V-48
V.12 Seasonal Mean Contaminant Dry Deposition Rates................ V-50
V.13 Geometric Mean Dry Deposition Rates at Monitoring Sites....... V-51
V.14 Seasonal Wet Deposition Contaminant Concentrations........... V-53
V.15 Seasonal Wet Deposition Contaminant Concentrations........... V-54
V.16 Multi-Element Scan Analysis of Metals in Rainwater........... V-56
V.17 Event Comparison of Rain Contaminant Concentrations and Runoff Concentrations....................................... V-58
V.18 Rooftop Runoff Contaminant Concentrations.................... V-61
V.19 Rooftop Runoff Contaminant Concentrations.................... V-62
V.20 Comparison of Rainfall Quality and Rooftop Runoff Contaminant Concentrations.. V-63
V.21 Comparison of Event Total Zinc Grab Sample Concentrations (mg/l) From a Sloping Roof Surface, Eaves Trough Sampler and Downspout... V-65
V.22 Comparison of Rooftop Runnoff and Stormwater Contaminant Concentrations.. V-66
V.23 Mean Contribution of Rooftop Loads to Stormwater Loads........ V-67

Chapter VI

Page

VI.1 Street Sweeper Removal Rates as a Functions of Street Surface Loads.......... VI-3
VI.2 Average Street Sweeper Removal Efficiencies of Total Solids, by Particle Size.......... VI-7
VI.3 Average Street Sweeper Removal Efficiencies of Various Parameters.......... VI-9
VI.4 Average Street Sweeper Removal Rates of Various Parameters Rates.......... VI-10
VI.5 Correlations (r) of Selected Parameters for Control Events... VI-12
VI.6 Statistical Analyses of the Effects of Street Sweeping Using Paired Data.......... VI-17
VI.7 Projected Reduction in Washoff From Streets at State Fair Due to Increased Sweeping.......... VI-20
VI.8 Projected Reduction in Washoff From Streets at Congress Due to Increased Sweeping.......... VI-21
VI.9 Projected Reduction in Washoff from Streets at Hastings Due to Increased Sweeping.......... VI-22
VI.10 Projected Reductions in Washoff During March With Intensive Initial Sweeping Followed by Normal Sweeping.......... VI-24
VI.11 Projected Reduction in Washoff Due to Improved Street Sweeper Efficiency at Hastings.......... VI-29
VI.12 Projected Reduction in Washoff Due to Improved Street Sweeper Efficiency at Congress.......... VI-30
VI.13 Projected Reduction in Washoff Due to Improved Street Sweeper Efficiency at State Fair.......... VI-31

FIGURES

Number Page

Chapter III

III.1 Sources of runoff for Lincoln Creek site (04086941)......... III-11
III.2 Sources of runoff for West Congress site (04086942)......... III-12
III.3 Sources of runoff for Rustler site (04086943)............... III-13
III.4 Sources of runoff for Post Office site (04086945)........... III-14
III.5 Sources of runoff for Burbank Street site (04087046)........ III-15
III.6 Sources of runoff for Hastings Street site (04087057)....... III-16
III.7 Sources of runoff for State Fair site (04087115)............ III-17
III.8 Sources of runoff for Wood Center site (04087133)........... III-18
III.9 Flow chart for DR3M model verification...................... III-20

Chapter IV

IV.1 Probability Functions for Suspended Solids, By Land Use..... IV-5
IV.2 Probability Functions for Total Phosphorus, By Land Use..... IV-6
IV.3 Probability Functions for 5-Day BOD, By Land Use............ IV-7
IV.4 Probability Functions for Total Lead, By Land Use........... IV-8
IV.5 Probability Functions for Total Zinc, By Land Use........... IV-9
IV.6 Probability Functions for Dissolved Lead, By Land Use....... IV-10
IV.7 Probability Functions for Dissolved Reactive Phosphorus, By Land Use.. IV-11
IV.8 Probability Functions for Total Solids By Land Use.......... IV-12
IV.9 Probability Functions for Volatile Suspended Solids By Land Use.. IV-13
IV.10 Probability Functions for Chloride By Land Use.............. IV-14
IV.11 Probability Functions for Ammonia N By Land Use............ IV-15
IV.12 Probability Functions for Total Kjeldahl N By Land Use...... IV-16
IV.13 Probability Functions for Total Organic N By Land Use....... IV-17
IV.14 Probability Functions for Nitrate-Nitrite N By Land Use..... IV-18
IV.15 Probability Functions for Fecal Bacteria By Land Use........ IV-30

Chapter V

Page

V.1 Particle Size Distribution of Street Dirt Total Solids........... V-4
V.2 Mean Concentration of Total Lead in Street Dirt.................. V-6
V.3 Mean Concentration of Total Phosphorus in Street Dirt............ V-7
V.4 Mean Concentration of Volatile Solids in Street Dirt............. V-8
V.5 Mean Concentration of Chemical Oxygen Demand in Street Dirt...... V-9
V.6 Size Distribution of Pollutants in Street Dirt at State Fair..... V-10
V.7 Size Distribution of Pollutants in Street Dirt at Congress....... V-11
V.8 Size Distribution of Pollutants in Street Dirt at Rustler Rough.. V-12
V.9 Size Distribution of Pollutants in Street Dirt at Rustler Smooth. V-13
V.10 Size Distribution of Pollutants in Street Dirt at Hastings....... V-14
V.11 Parking Lot Loads, Rainfall, Sweeping Dates, Ruslter, Summer 1981 V-18
V.12 Street Loads, Rainfall, Sweeping Dates, State Fair, Spring 1981.. V-19
V.13 Street Loads, Rainfall, Sweeping Dates, State Fair, Summer, 1981. V-20
V.14 Street Loads, Rainfall, Sweeping Dates, State Fair, Fall, 1981... V-21
V.15 Street Loads, Rainfall, Sweeping Dates, Congress, Spring, 1981... V-22
V.16 Street Loads, Rainfall, Sweeping Dates, Congress, Summer, 1981... V-23
V.17 Street Loads, Rainfall, Sweeping Dates, Congress, Fall, 1981..... V-24
V.18 Street Loads, Rainfall, Sweeping Dates, Hastings, Spring, 1981... V-25
V.19 Street Loads, Rainfall, Sweeping Dates, Hastings, Summer, 1981... V-26
V.20 Street Loads, Rainfall, Sweeping Dates, Hastings, Fall, 1981..... V-27
V.21 Average Net Change in Street Loads Following Rainfall at Two Sites.. V-38
V.22 Probability of Solids Loads in Events and on Street at State Fair.. V-41
V.23 Probability of Volatile Solids in Events and Streets at State Fair.. V-42
V.24 Probability of Total Phosphorus Loads in Events and Streets at State Fair... V-43

Chapter VI

VI.1 Street Sweeper Removal Function at State Fair................. VI-4
VI.2 Street Sweeper Removal Function at Congress................... VI-5
VI.3 Street Sweeper Removal Function at Hastings................... VI-6
VI.4 Suspend Solids, Paired Events Only, State Fair/Wood Center.... VI-13
VI.5 Suspend Solids, Paired Events Only, Rustler/Post Office....... VI-14
VI.6 Suspend Solids, Paired Events Only, Hastings/Burbank.......... VI-15
VI.7 Street Sweeper Removal Functions at State Fair................ VI-26
VI.8 Street Sweeper Removal Functions at Congress.................. VI-27
VI.9 Street Sweeper Removal Functions at Hastings.................. VI-28

CHAPTER I.

INTRODUCTION

This volume presents the technical findings, conclusions and recommendations of a study of the characteristics, sources and controls of urban stormwater pollution in Milwaukee, Wisconsin. This study was conducted by the Wisconsin Department of Natural Resources (WDNR), with major subcontracts to the U. S. Geological Survey (USGS), and to the Southeastern Wisconsin Regional Planning Commission (SEWRPC). It was funded largely by the U. S. Environmental Protection Agency (Grant No. 005432-01-2) as one of the 28 studies undertaken by the Nationwide Urban Runoff Program (NURP).

NURP was developed in 1978 to remedy the inadequacy of data regarding urban stormwater characteristics, impacts and controls. The 28 NURP studies are located around the United States, and represent a variety of regional and hydrological conditions. This project was choosen to represent conditions around the Great Lakes.

OBJECTIVES

The Milwaukee NURP study has had three principle objectives: 1) to characterize the urban stormwater quality of a major midwestern city; 2) to evaluate the various sources of urban stormwater contaminants; and 3) to evaluate the effectiveness, cost and feasibility of street sweeping as an urban stormwater management practice. This volume contains the technical findings, conclusions and recommendations related to urban stormwater quantity, quality, impacts, pollutant sources and street sweeping effectiveness.

METHODOLGY

To characterize urban stormwater quality, stormwater discharge from eight paired basins in Milwaukee County was monitored. The eight paired basins represent four major urban land uses, including commercial, high and medium density residential areas and parking lots. The basins are small (less than 25 hectares), relatively homogeneous, and are drained by separate storm sewers. The paired basins are either contiguous, or within a quarter mile of each other. Event runoff was monitored at each site using one minute stage recorders and automatic flow proportional composite samplers. A single event mean concentration and total event load was determined for each parameter that was analyzed for each monitored event. A total of 450 events at the eight stations were monitored. Rainfall at each station was also recorded at one minute intervals.

To evaluate the various sources of urban stormwater contaminants, a multi-faceted monitoring program was developed. A comprehensive street surface sampling program was maintained at one of each of the paired water quality stations. A total of 554 street surface contaminant samples were collected, including 142 accumulation, 113 street sweeper removal, and 19 rainfall washoff evaluations. In addition, atmospheric wetfall and dryfall monitoring was conducted at eight locations in or nearby the water quality monitoring sites. A total of 242 wetfall and 112 dryfall samples were collected. Rooftop runoff from three houses was monitored, and a total of 48 composite rooftop runoff samples were collected. Through an analysis of stormwater contributions from street surfaces, rooftops, and precipitation, a mass balance of stormwater contaminant sources was achieved.

A threefold approach was taken to evaluate the effects of street sweeping as an urban stormwater management practice. First, an evaluation of in-situ street sweeper contaminant removal was conducted, as mentioned previously. Secondly, the water quality impacts of street sweeping were evaluated through use of a conventional test and control experimental design. Within each basin pair, one watershed was designated as the test site, and the other the control site. Street sweeping in the control sites was maintained at the usual or baseline frequencies that are normally maintained by the respective municipalities for aesthetic reasons. Street sweeping in the test sites alternated between corresponding baseline frequencies (control periods) and accelerated frequencies (test periods). By comparing the stormwater quality between test and control sites between test and control periods, an evaluation of the water quality impacts of street sweeping was achieved. Thirdly, two models were developed in this project to extrapolate the findings of this project to other areas and/or sweeping frequencies.

RESPONSIBILITIES

The field work supporting Volume I was conducted by the WDNR and the USGS. Department personnel conducted the street surface, atmospheric wet and dry, and the rooftop monitoring programs. In addition, they were responsible for the data management and analysis for these programs as well as for the water quality evaluation. They also developed one of the two urban runoff/street sweeping models produced in this study. The USGS performed the rainfall and runoff monitoring, the hydrologic analysis, and the preparation and sieving of the street surface samples. Additionally, the Wisconsin State Lab of Hygiene performed the chemical analyses for the various monitoring programs.

SCOPE

The data collection for this volume began in the spring of 1980 and was completed by August 1982. The results in this volume can be applied to other urban areas with similar meterologic, atmospheric and cultural conditions. The contents of Volume II compliment this volume with an evaluation of the cost and feasibility of urban management practices. Together the volumes provide a comprehensive evaluation of urban stormwater problems and concerns. This Volume and Volume II will be of use to city and state planners and engineers, and to those with a need to develop a better understanding of the impacts and controls of existing or planned urban development.

CHAPTER II.

CONCLUSIONS AND RECOMMENDATIONS

The purpose of Chapter II is to summarize the conclusions at the end of each chapter in Volume I and to make recommendations based on the findings.

CHARACTERISTICS OF URBAN STORMWATER

1. Among the urban areas of this study, stormwater runoff concentrations and loads for total lead and suspended solids were highest from the commercial areas, followed by high density and medium density residential areas, respectively. Annual loads of suspended solids from the high density residential areas and the commercial areas are two and five times higher respectively than from the medium density residential areas, and annual loads of total lead were four and thirteen times higher, respectively. A ranking of pollutant loads for urban land uses monitored in this study and previous studies in the Milwaukee area indicates that commercial, industrial and freeway land uses are most critical. Because of the wide range in pollutant loads from various urban land uses, an urban nonpoint source pollution control program should be tailored to the specific land uses where it can be applied most cost-effectively.

2. Fecal coliform counts in urban runoff usually greatly exceed safe bathing water criteria. The high fecal counts suggest that body contact be limited in urban streams and that levels of fecal coliforms in receiving waters be closely monitored following rainfall.

IMPACT OF URBAN STORMWATER

1. This project did not collect any water quality data in the receiving streams, but results from previous monitoring programs on the Menomonee River were used to evaluate the impact of urban stormwater in Milwaukee County.

   The quality of the Menomonee River decreases as it flows from its agricultural head waters through Milwaukee to Lake Michigan. This degradation is reflected by the decrease in the numbers of fish and increase in the level of pollutants in the water and bottom sediments. The fish population may be responding to a number of variables, including accumulated toxins in bottom sediments and changes in the hydrology and morphology of the river. Yet, in the absence of significant known point sources of pollution, the dramatic decline in the quality of the river system as it flows through Milwaukee demonstrates that urban stormwater can seriously degrade the quality, aquatic viability, and beneficial uses of receiving waters. To restore the full quality of this river system, an urban as well as an agricultural nonpoint source management program is needed.

2. Urban and agricultural land uses in Wisconsin generate similar stormwater loads of suspended solids and total phosphorus on a unit area basis. Agricultural land uses generate less volume of runoff but higher concentrations of these pollutants than urban areas. Both stormwater loads and concentrations of lead, and of most other heavy metals, are much higher from urban areas than from agricultural areas. For an effective statewide nonpoint source pollution control program, urban areas as well as agricultural areas need to be managed properly.

3. The amounts of total phosphorus and BOD discharged from residential areas via treated secondary wastewater is greater than the amounts contained in stormwater runoff. However, the suspended solids discharged in residential stormwater runoff is greater than in treated secondary effluent. The relative sources of specific pollutants in receiving waters need to be addressed when reviewing water quality problems and considering alternative management programs.

SOURCES OF URBAN STORMWATER CONTAMINANTS

1. Most of the sediments and toxic metals in urban runoff originate in washoff from streets. However, other than in the fall, total phosphorus loads observed in individual stormwater events are generally much greater than total loads observed in the streets, indicating that most phosphorus originates from lawns and trees. The relative significance of the sources of stormwater contaminants strongly affects the control of those contaminants by street sweeping.

2. Street loads of sediment and toxic metals are at their annual peak at the onset of winter snowmelt and spring rainfalls. If not swept up, this residue, which has accumulated throughout the winter, is quickly washed into receiving waters by spring rains. As much as one-fifth to one-third of total annual stormwater load of sediment may occur in the first month of spring runoff.

   Once the streets are "cleaned" of winter residues, however, (by repeated sweeping and/or rainfall washoff) street loads fluctuates between the limits of an upper and lower bounds unique to each site. The lower bounds are dependent primarily on street surface texture and condition. They represent a reservoir of street loads that is the cleanest condition expected for the street. Street sweeping at this level is not effective at further reducing street loads and rainfalls at this level tend to wash or carry as much material onto the street as off of it. The upper bounds are dependent upon land use intensity, traffic patterns, and street surface texture and conditions, which combine to effect the rate of accumulation of street surface material. They are approximately two to three times the level of the lower bounds, and are the maximum street load level observed in this study before street sweeping, rainfall or winds swept, washed or otherwise removed a portion of the street load. Street loads of total solids ranged from 5 to 15 grams per curb meter for a medium density residential area and 40 to 80 grams per curb meter for a commercial area.

3. Atmospheric dry deposition of solids, lead and COD increases with increasing residential density and intensity of commercial and industrial land uses. Atmospheric dry deposition rates of sulfate and lead are constant throughout the year, showing little seasonal variation. The wet and dry atmospheric deposition of solids and phosphorus is highest in spring and lowest in winter, probably related to the seasonal variation in exposed soil available to wind erosion.

4. No spatial or land use related variations were observed among concentrations of contaminants in rainfall. The monitored acidity and sulfate rainfall concentrations are slightly higher in the Milwaukee area than averages from other sites monitored in Wisconsin. For low intensity land uses, such as medium density residential areas, contaminants in rainfall can provide as much as 10 to 20 percent of the total stormwater loads of some pollutants. These contributions decrease with increasing urban density, because washoff from streets, parking lots and roof tops become more important. Management alternatives to reduce this portion of the pollutants carried by stormwater could be more effective if directed at reducing the sources of atmospheric contamination, such as fugitive dust (wind erosion) and industrial and automotive emissions.

5. Rooftop runoff contaminant concentrations generally increase with increasing residential density and the intensity of commercial and industrial land uses. However, the relative contribution of rooftop runoff contaminants to total stormwater pollutant loads decrease because of the importance of other contaminant sources associated with these land uses. For example, galvanized steel eaves troughs and downspouts on residential roofs are major sources of zinc. For medium density residential areas, an average of 23% of the water, 7% of the suspended solids and virtually all of the zinc in stormwater came from rooftops. Management of residential rooftop runoff through removal of zinc sources, and routing of downspout outlets to pervious areas could reduce stormwater volumes and the concentrations of some stormwater contaminants.

6. In medium and high density residential areas, runoff originating from lawns is of the same order of magnitude as that from connected rooftops, roughly 10-20 percent of the total runoff for most rainfalls totalling less than 2 inches. In commercial areas, runoff from pervious surfaces is less than 5 percent of the total runoff, while runoff from connected rooftops is 30-40 percent of the total. The control of runoff from lawns should have a lower priority than other sources in an established urban area.

MANAGEMENT ALTERNATIVES FOR URBAN STORMWATER

1. Because of the extreme variability in urban stormwater quality, and of the difficulties in taking comprehensive and representative samples, this project was unable to statistically demonstrate a water quality impact due to accelerated street sweeping. Rather, the projected water quality benefits of street sweeping were derived through the use of two models developed in this study.

Street sweeping is most effective as a stormwater pollution control practice under two conditions: 1) early in the spring when streets are laden with winter residue, and 2) in the fall, following leaf fall. Following snowmelt, an intensive street sweeping program to clean city streets as early as possible is recommended. An area may need to be swept more than once to be adequately cleaned. Early intensive street sweeping may reduce the total stormwater pollutant load for the first month of the season by as much as 50 percent. In the fall, in areas with heavy leaf accumulations, intensive street cleaning and leaf pick up are recommended. Use of leaf rakes and/or vacuum street cleaners may be used to augment or replace sweepers. Concomitant efforts should also be made to encourage residents to bag or pile their leaves on the lawn next to the curb, rather than raking them into the gutters.

For most urban areas, street sweeping appears to have a relatively low effectiveness from late spring (once the streets are cleaned of accumulated winter loads) until early fall (prior to the onset of leaf fall). Intensive street sweeping (two or three times per week) during this period will result in limited stormwater pollution reductions, but it is doubtful that it will exceed ten percent.

2. Urban areas with the most hydrologically impervious surfaces generate the most stormwater runoff. This increased runoff not only creates greater downstream flooding problems, but also carries with it more stormwater pollution. The hydrologic response of an area may be the most significant factor determining the subsequent level of stormwater pollution. Consequently, stormwater management is an essential part of any urban stormwater control program particularly in developing areas. In many established urban areas, simple redirection of rooftop downspouts away from the stormwater conveyance system may reduce yields of stormwater runoff and associated pollutants.

CHAPTER III

RUNOFF VOLUMES AND RAINFALL

INTRODUCTION

Rainfall and runoff volumes were monitored by the U.S. Geological Survey (USGS) as part of the Milwaukee Nationwide Urban Runoff Program. The collected data were used to characterize the meterological conditions for the study period, to evaluate the runoff characteristics of the basins, to provide flow information for computing the pollutant loads transported from the basins, to develop predictive equations for transferring the data to other unmonitored basins, and to determine the sources of runoff.

The study sites consisted of eight small, homogeneous storm-sewered basins which were paired according to four land types of land uses--commercial, parking lot, high density, and medium density residential. Monitoring of the rainfall and runoff started at the commercial and parking lot sites on April 1, 1980. The medium density residential sites were started on June 1, 1980, and the high density sites on April 1, 1981. All the sites were operated until June 30, 1982. Rainfall and discharge were recorded at 1-minute intervals during the active runoff periods and runoff samples were obtained on a flow proportional basis using an automated sampler activated by a Marsh-McBirney flowmeter. A complete description of the physical parameters of the basins, the monitoring equipment, and the procedures used to collect and process the samples are found in Volume III--Study Site Characteristics, Experimental Methods and Quality Assurance Program.

During 1980 many modifications were made to the monitoring and sampling equipment to increase their reliability. During 1981 the success rate for recording rainfall and runoff volumes was increased but difficulties were still encountered with the water-quality sampler equipment. The two medium density sites were temporarily out of service due to bridge reconstruction in 1981. The Hastings site was out from August 1, 1981, to March 1, 1982, and the Burbank site from November 30, 1981, to April 15, 1982. The State Fair commercial site was plagued by electric service disruptions during 1980 and had a combination high velocity and high lift problem which severely reduced the number of sampled events. The situation was improved in 1981 by modification to the automated sampler and installation of a baffle in the storm sewer. The high density residential sites of West Congress and Lincoln Creek had varying backwater and many event samples had to be discarded.

RAINFALL AND RUNOFF VOLUMES

The runoff volumes for the sampled events are the result of both monitored and modeled data using the USGS Distributed Routing Rainfall-Runoff Model (DR3M) (Alley and Smith, 1982). The model was run to compute runoff volumes for those events which did not have observed values due to recorder or flowmeter malfunction. A 1-minute routing interval was used for all storms except those prior to June 1980 for which a 5-minute interval was used. Rainfall for each event was compared between the sites and when absent or invalid the unit rainfall from the closest site was used as input to the model.

Rainfall Volumes

There were between 51 and 84 runoff events for the sites started in 1980 which had samples collected and analyzed during the study period. The high density residential sites started in 1981 had 31 and 39 events for which samples were obtained. Table III.1 presents a statistical summary of the rainfall for each of the sites.

The mean rainfall ranged from 1.12 to 1.64 cm over the basin with a minimum volume of 0.03 cm and a maximum of 12.37 cm.

TABLE III.1

RAINFALL FOR SAMPLED EVENTS, CM

Study area	Number of events	Mean	Standard deviation	Minimum	Maximum
			Commercial		
State Fair	53	1.12	0.82	0.10	3.23
Wood Center	67	1.33	1.29	0.13	8.23
			Parking Lots		
Rustler	71	1.30	1.28	0.10	7.19
Post Office	84	1.40	1.45	0.03	9.04
			High Density Residential		
Lincoln Creek	39	1.64	1.82	0.30	9.04
West Congress	31	1.26	0.96	0.23	4.24
			Medium Density Residential		
Hastings	51	1.34	1.77	0.03	12.37
Burbank	61	1.44	1.86	0.10	12.37

Runoff Volumes

Table III.2 shows a statistical summary of the runoff for each of the sites.

TABLE III.2

RUNOFF FOR SAMPLED EVENTS, CM

Study area	Number of events	Mean	Standard deviation	Minimum	Maximum
		Commercial			
State Fair	53	0.75	0.61	0.04	2.32
Wood Center	67	1.09	1.23	0.02	7.90
		Parking Lots			
Rustler	72	1.15	1.23	0.06	7.03
Post Office	84	1.27	1.34	0.01	8.36
		High Density Residential			
Lincoln Creek	41	0.74	1.52	0.07	7.53
West Congress	31	1.26	0.96	0.23	4.24
		Medium Density Residential			
Hastings	55	0.46	0.97	0.01	7.13
Burbank	61	0.54	0.90	0.01	5.73

The mean runoff varies from 0.46 to 1.27 cm per basin. The amount of runoff is directly related to the percent connected impervious area within the basin.

Duration of Runoff

The frequency and duration of runoff in small, storm-sewered, urban basins differs significantly from that in unimproved natural drainage basins. Natural drainage basins modify runoff characteristics by infiltration, by flow attenutation from vegetation and terrain, and by storage. Urban drainage basins have been designed to rapidly transport excess rainfall through gutters and pipes out of the basin. In natural basins storm runoff typically lasts for hours or days as contrasted to minutes or hours for sewered urban basins. Many small storm runoff events, less than 1 cm over the basin, lasted less than one-half hour and generally provided too few water quality samples to accurately characterize the event.

Table III.3 shows a summary of the storm durations for the basins monitored in this study.

TABLE III.3

STORM DURATION FOR SAMPLED EVENTS, HOURS

Study area	Number of events	Mean	Standard deviation	Minimum	Maximum
Commercial					
State Fair	53	5.6	3.9	1.7	23.3
Wood Center	67	5.8	4.4	1.7	22.9
Parking Lots					
Rustler	71	6.1	3.8	1.8	22.0
Post Office	84	6.4	4.2	1.8	22.0
High Density Residential					
Lincoln Creek	41	5.9	3.3	2.4	16.5
West Congress	31	6.0	3.4	1.7	14.8
Medium Density Residential					
Hastings	54	5.9	3.5	1.8	16.5
Burbank	61	5.1	2.9	2.0	16.5

Runoff Coefficients

The amount of runoff generated by different volumes of rainfall can be expressed as a runoff coefficient (Rv). This value is defined as the ratio of the total runoff volume to the total rainfall volume. As reported by Pitt (1983), the Rv value includes the effects of evaporation, detention/storage, soil infiltration, and the amount of directly connected impervious area within the basin. The Rv value will vary considerably from storm to storm because of soil-moisture conditions, the rainfall duration, and the rainfall intensity. For example, small amounts of rainfall will typically show a lower Rv than do large rains because a greater percentage of the total rain either evaporates or is retained by depression storage instead of showing up as runoff from the basin.

Table III.4 presents a summary of the runoff coefficients observed for the eight monitored sites over the 2 1/2-year study period.

TABLE III.4

RUNOFF COEFFICIENT (Rv) FOR SAMPLED EVENTS

Study area	Number of events	Mean	Standard deviation	Minimum	Maximum	Percent connected impervious area
			Commercial			
State Fair	53	0.62	0.15	0.26	0.78	76.8
Wood Center	67	0.73	0.18	0.15	0.97	80.6
			Parking Lot			
Rustler	71	0.88	0.12	0.40	1.01	99.0
Post Office	84	0.82	0.13	0.56	1.04	98.0
			High Density Residential			
Lincoln Creek	39	0.33	0.15	0.18	0.85	44.0
West Congress	31	0.33	0.09	0.16	0.64	39.0
			Medium Density Residential			
Hastings	51	0.28	0.10	0.02	0.58	30.0
Burbank	61	0.33	0.22	0.01	0.64	30.0

The summary of the Rv's in Table III.4 shows a considerable range in the Rv value within each site and between the different land use categories. The absolute range of the Rv values at the Lincoln Creek site was from 0.16 to 0.64. At the Wood Center commercial site, the range was even greater, 0.15 to 0.97. Comparisons of the mean of the Rv's between the test and control basins of the paired sites indicates that the hydrologic response of these basins is very similar. The largest difference in the mean Rv for paired basin was 15 percent for the commercial sites. The medium density and high density residential sites had mean Rv values approximating 0.33. The percent connected impervious area was strongly correlated with the mean Rv value--as the amount of directly connected impervious area increased, so did the Rv value.

COMPARISON OF THE OBSERVED RAINFALL AND RUNOFF TO ANNUAL AND AVERAGE VALUES

To assess the success or failure of the monitoring program and to put the results of the study into a larger time frame, it is important to compare the observed data to the annual and long-term average data. Long-term weather records analyzed by the Southeastern Wisconsin Regional Planning Commission (SEWPRC) were used to evaluate the normality of the 1980-82 data-collection period.

Regression equations were developed for each of the eight monitored sites relating the observed rainfall to the observed runoff. These equations were then used to estimate the expected runoff resulting from the long-term averaged daily rainfall totals. These estimated daily runoff values were compared to the actual event monitored runoff for the 1980-82 calendar year.

Regression Equations

The observed runoff and rainfall were used in a linear regression model to develop site specific equations for computing storm runoff using observed rainfall volumes as the independent variable. Table III.5 lists the equations for each site and their associated coefficient of determination (r^2). As shown in Table III.5 the r^2 values ranged from 0.95 to 0.98 indicating an excellent relationship of rainfall to runoff for each site.

TABLE III.5

REGRESSION EQUATIONS FOR PREDICTING RUNOFF VOLUME

Study area	Equation	r^2	Degrees of freedom
	Commercial		
State Fair	$y = 0.731 X -0.025$	0.98	66
Wood Center	$y = 0.947 X -0.067$	0.98	66
	Parking Lots		
Rustler	$y = 0.949 X -0.024$	0.97	70
Post Office	$y = 0.916 X -0.003$	0.98	83
	High Density Residential		
Lincoln Creek	$y = 0.819 X -0.221$	0.92	38
West Congress	$y = 0.530 X -0.0674$	0.92	30
	Medium Density Residential		
Hastings	$y = 0.557 X -0.101$	0.97	50
Burbank	$y = 0.476 X -0.058$	0.97	60

Because rainfall is log normally distributed a linear regression model using the natural log-transformed rainfall and runoff values was developed. The equations resulted in coefficients of determination which were lower than those for the nonlog-transformed values and were therefore not used in subsequent analyses.

Annual and Long-Term Average Rainfall

Daily rainfall recorded at the U.S. Weather Bureau gages at Mt. Mary College and West Allis were used with the regression equations to estimate the annual storm runoff expected from each of the monitored basins. The U.S. Weather Bureau gages were representative of the monitored area with the Mt. Mary College gage located near the Burbank site in the northwest and the West Allis gage between the Wood Center and State Fair sites in the south. The effective rainfall was defined to be greater than 0.254 cm accumulation per day. Using this definition, the 40-year average annual effective rainfall recorded at the U.S. Weather Bureau gage at Mitchell Field in southeast Milwaukee is 71.8 cm. The effective rainfall recorded at the Mt. Mary College and West Allis gages for the 1980 to 1982 calendar years is as follows:

	1980 (cm)	1981 (cm)	1982 (cm)
Mt. Mary College	65.3	66.0	56.7
West Allis	76.8	76.3	70.9

The 1982 calendar year was drier than 1980 and 1981 and for all 3 years less rain was recorded for the Mt. Mary College gage.

Predicted Runoff Versus Observed Runoff

The original design for this project planned for sampling of all storm-event runoff. Difficulties with equipment operation, field servicing, and service interruptions prevented this goal from being achieved. After resolving the problems with the flow monitoring and recording equipment, there were still events lost due to sampling equipment failure.

A comparison of the observed runoff and the predicted runoff from each site as computed using the regression equations with the storm-event daily rainfall is in Table III.6.

Table III.7 lists the percentage of the total predicted runoff from each basin for which water quality samples were analyzed.

TABLE III.6

OBSERVED AND PREDICTED RUNOFF FOR ALL SITES, CM

Study area	1980 runoff		1981 runoff		1982 runoff*	
	Observed	Predicted	Observed	Predicted	Observed	Predicted
			Commercial			
State Fair	6.6	52.1	20.6	52.1	13.0	14.6
Wood Center	32.5	62.0	29.7	62.2	11.2	17.2
			Parking Lot			
Rustler	31.8	58.7	34.5	51.8	17.6	19.4
Post Office	41.9	59.4	59.2	59.7	12.7	19.2
			High Density Residential			
Lincoln Creek	---	---	26.9	29.7	4.1	8.7
West Congress	---	---	10.7	26.2	4.8	8.1
			Medium Density Residential			
Hastings	14.2	22.6	9.6	24.4	4.0	8.6
Burbank	13.2	22.9	18.0	23.9	1.5	8.6

*Runoff through June 30, 1982.

TABLE III.7

RATIO OF OBSERVED TO PREDICTED RUNOFF FOR ALL SITES, PERCENT

Study area	1980	1981	1982
		Commercial	
State Fair	13	40	89
Wood Center	52	48	65
		Parking Lot	
Rustler	54	58	91
Post Office	71	87	66
		High Density Residential	
Lincoln Center	--	91	47
West Congress	--	41	59
		Medium Density Residential	
Hastings	62	39	47
Burbank	57	75	17

As would be expected, the success of the monitoring efforts, as measured by the percentage of the predicted runoff for which samples were analyzed, improved with time. By 1982 many of the equipment and field service difficulties had been eliminated and for most sites it was the most successful monitoring period. Volume III of this report describes the many modifications that were required to improve the reliability and usefulness of the monitoring and sampling equipment. The major modifications to the Marsh-McBirney flowmeter included installation of a drying column to remove condensation from the depth-sensing system, use of a voltage surge protector to prevent damage from lightning strikes to the incoming powerlines, and positioning the oriface of the depth-sensing system upstream from the turbulence caused by the velocity sensor. A serious problem caused by an electrical ground loop between an external recorder and the velocity sensor was not properly diagnosed until the end of the data collection. This ground loop resulted in the periodic dissolution of the upstream carbon electrode of the velocity probe and necessitated the replacement of four of the velocity sensors. The technical solution to this problem requires the use of a self-powered isolation transformer between the output circuit of the flowmeter and the external recorder.

The complexity of the monitoring system tended to increase the probability that component failure or incomplete field servicing would occur and result in some unsampled events.

SOURCES OF RUNOFF

Each of the monitored basins was selected because of its homogeneous land use, small size, and close proximity to another similar basin. This attempt at uniformity was to isolate the relative importance of a particular land use on producing urban nonpoint source pollution loads. However, this uniformity also allows the evaluation of the source of runoff as related to the percentage of the basin covered by impervious surfaces and to the infiltration capacity of the pervious land surface. The calibrated and verified USGS Distributed Routing Rainfall Runoff model was used to determine the percent runoff contributed from connected impervious surface and the pervious surfaces for each basin over a range of storm rainfalls.

The connected impervious areas within urban basins are generally street surfaces and rooftops. It is important to understand the relationship between the various sources of runoff to design an effective management plan for reducing the nonpoint source pollutant load. If, for example, only 30 percent of the connected impervious area could be cleaned by mechanical sweeping, then the load from the remaining 70 percent of the contributing area would mask the reduction in the pollutant load from that basin.

Type of Analysis

The USGS DR3M model which was used to calculate the runoff volumes for selected events was run on 1-hour duration storms for rainfalls totaling 0.1, 0.2, 0.5, 0.75, 1.0, 2.0, 3.0, 4.0, and 5.0 in. A rainfall of 1.0 in. in an hour has a recurrence interval of approximately 2 years, which means that each year there is a 50 percent chance that such a storm will occur.

Figures III.1 to III.8 show the runoff contribution (in percent) for each site from the directly connected impervious area, the directly connected rooftops, and the pervious area for each of the 1-hour rainfalls. The high density residential sites (Figures III.1 and III.2) show the most pronounced increase in pervious area runoff with increasing amounts of rainfall. The commercial sites (Figures III.7 and III.8) have less pervious area and, therefore, show a smaller contribution from the pervious area. Figures III.1 to III.8 also show the runoff contribution from connected rooftops. The percent of the total runoff attributable to rooftops varies from 7 percent at the Lincoln Creek site to more than 20 percent at the Wood Center site.

Use of the Data

The data from Figures III.1 to III.8 can be used to determine the relative impact of various management practices on controlling urban nonpoint-source pollutant runoff. The larger the percentage of the total annual runoff which is generated from pervious or impervious areas which are not susceptible to management practices, the more difficult is the problem of reducing the nonpoint source load from that basin.

The relative pollutant load generated from pervious areas is low for 1-hour duration rainfalls with less than 1 in. accumulation. The high density residential areas had the largest contribution with 10 percent for the Lincoln Creek site and 12 percent for the West Congress site. At these sites the

FIGURE III-1
SOURCES OF RUNOFF FOR LINCOLN CREEK SITE (04086941) FOR 1 HOUR DURATION STORMS

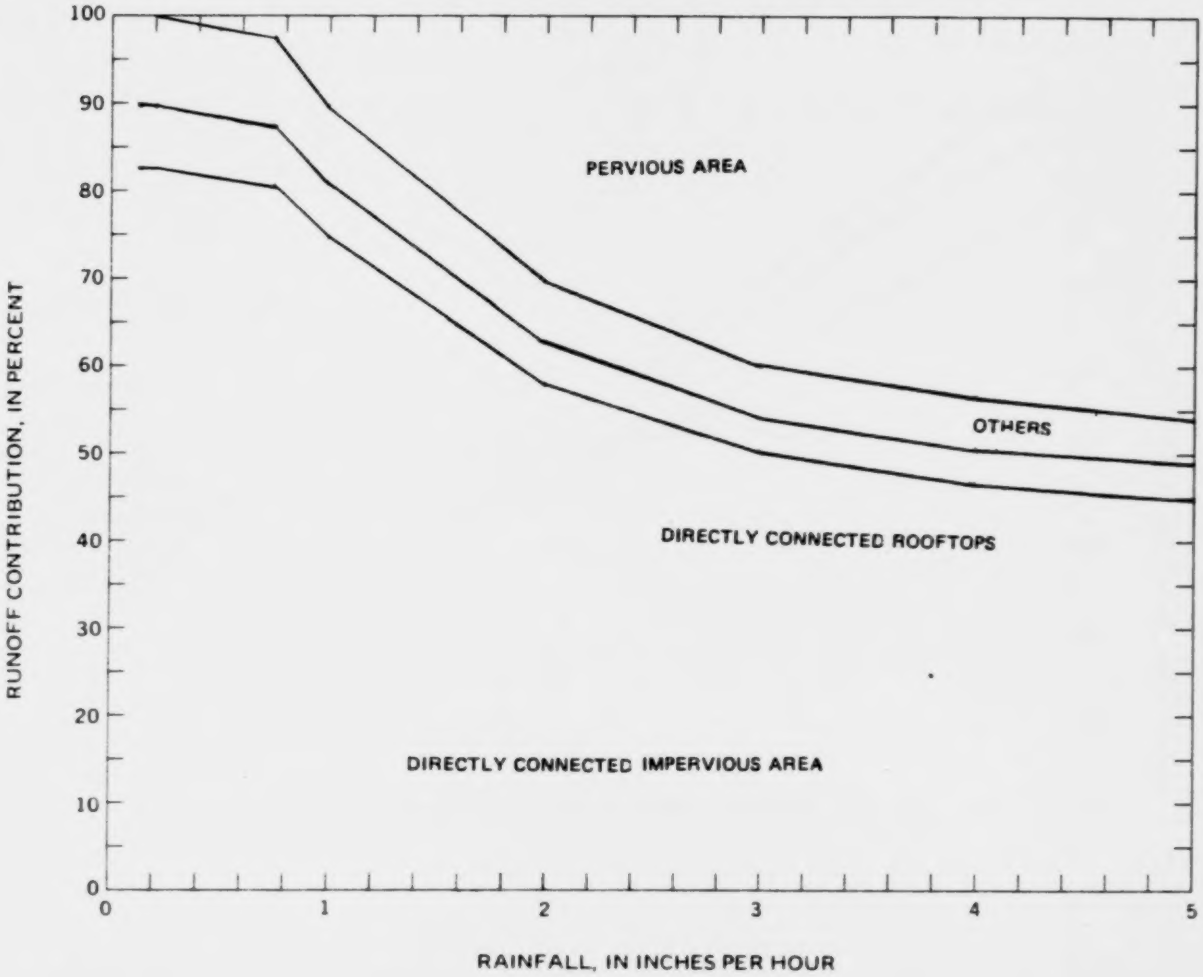


FIGURE III-2
SOURCES OF RUNOFF FOR WEST CONGRESS SITE (04086492) FOR 1 HOUR DURATION STORMS

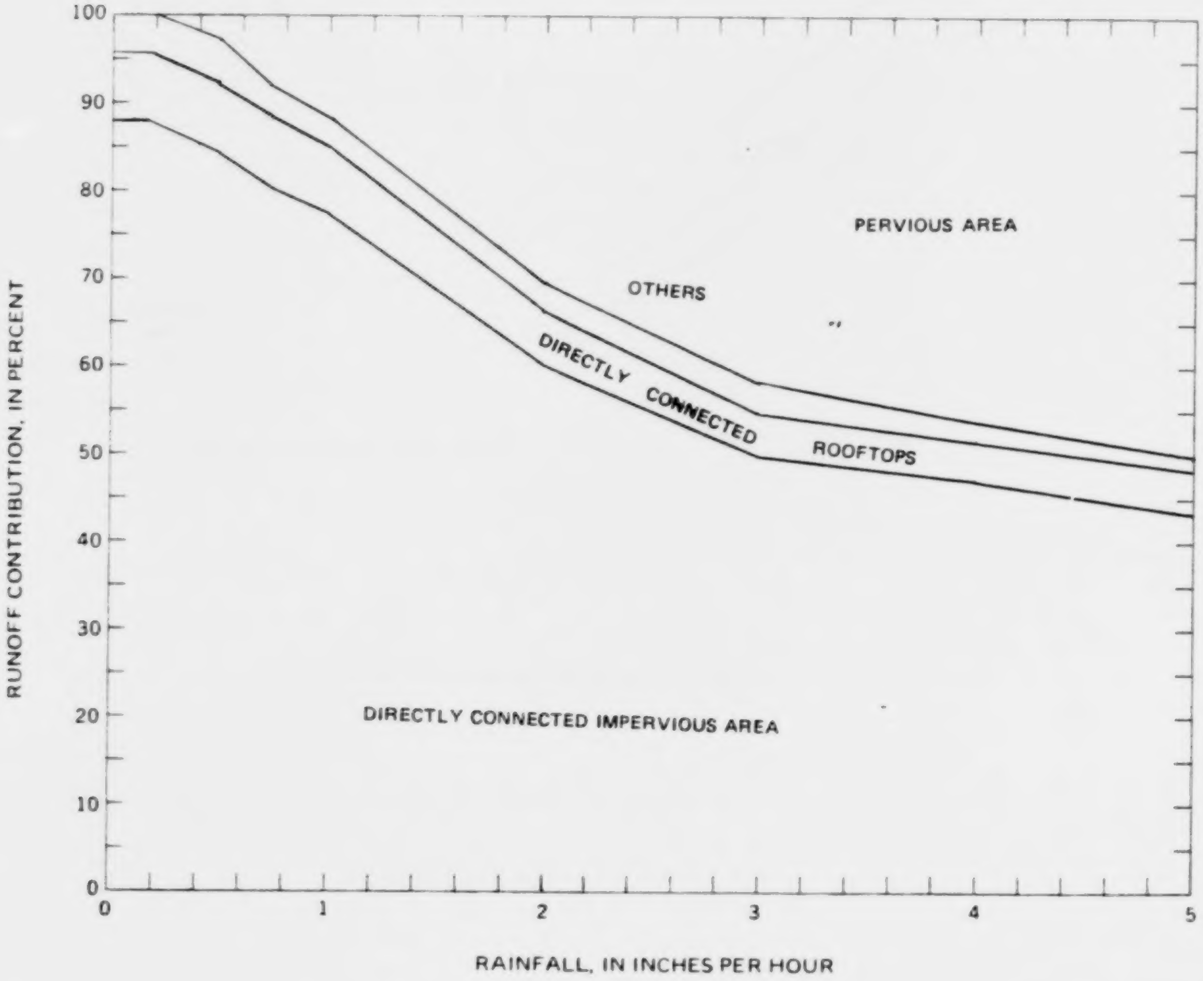


FIGURE III-3

SOURCES OF RUNOFF FOR RUSTLER SITE (04086493) FOR 1 HOUR DURATION STORMS

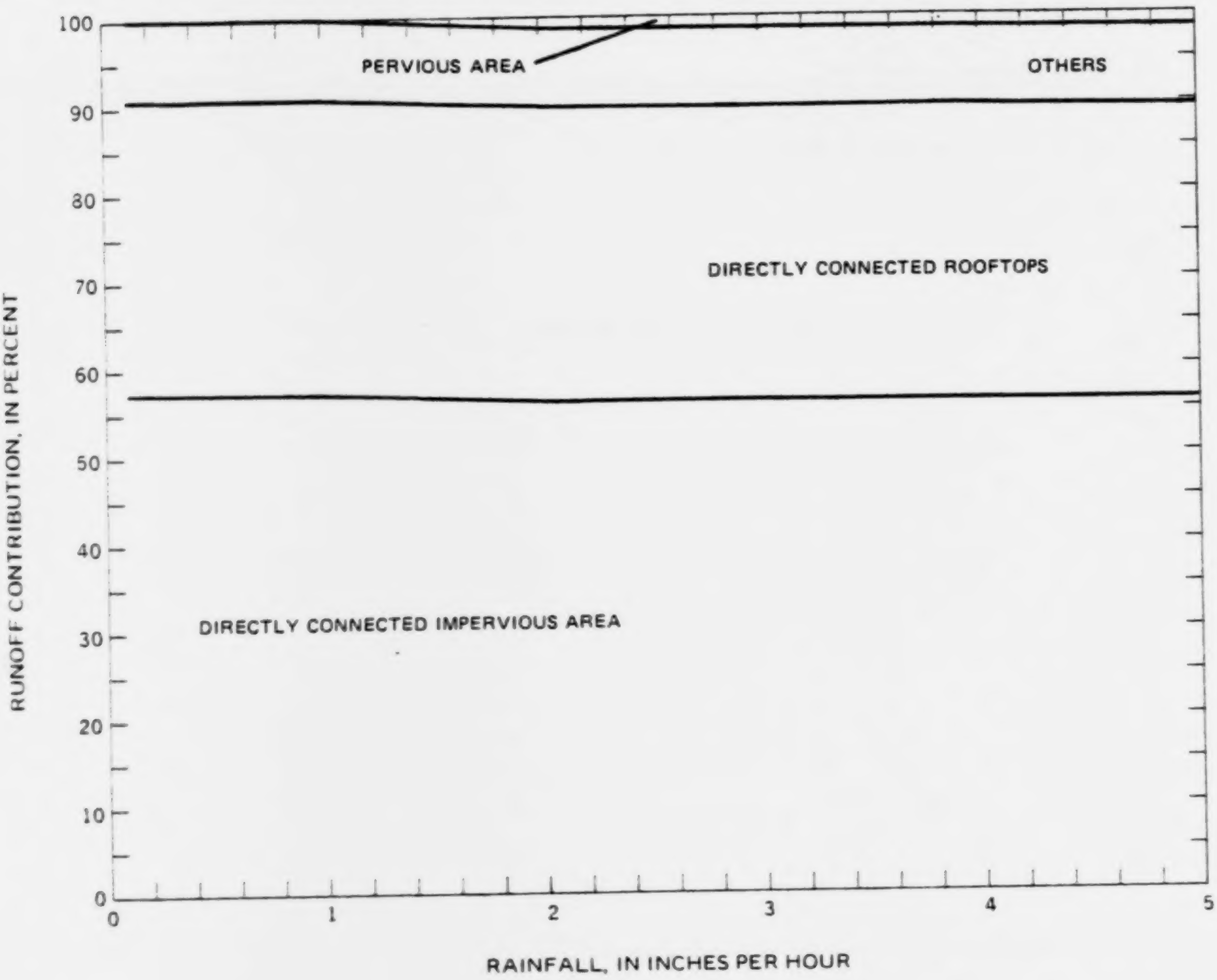


FIGURE III-4

SOURCES OF RUNOFF FOR POST OFFICE SITE (04086495) FOR 1 HOUR DURATION STORMS

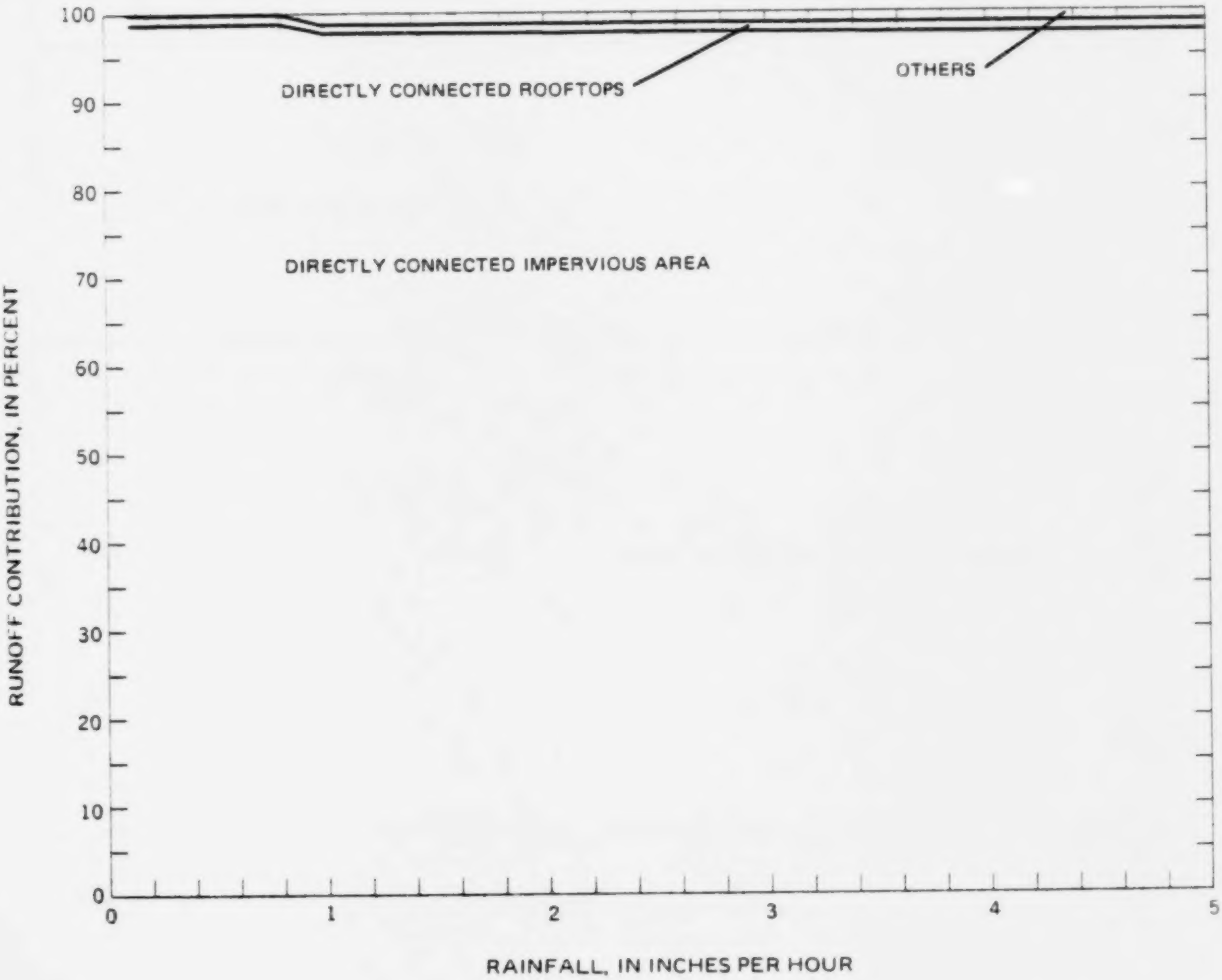


FIGURE III -5
SOURCES OF RUNOFF FOR BURBANK STREET SITE (04037056) FOR 1 HOUR STORM DURATION

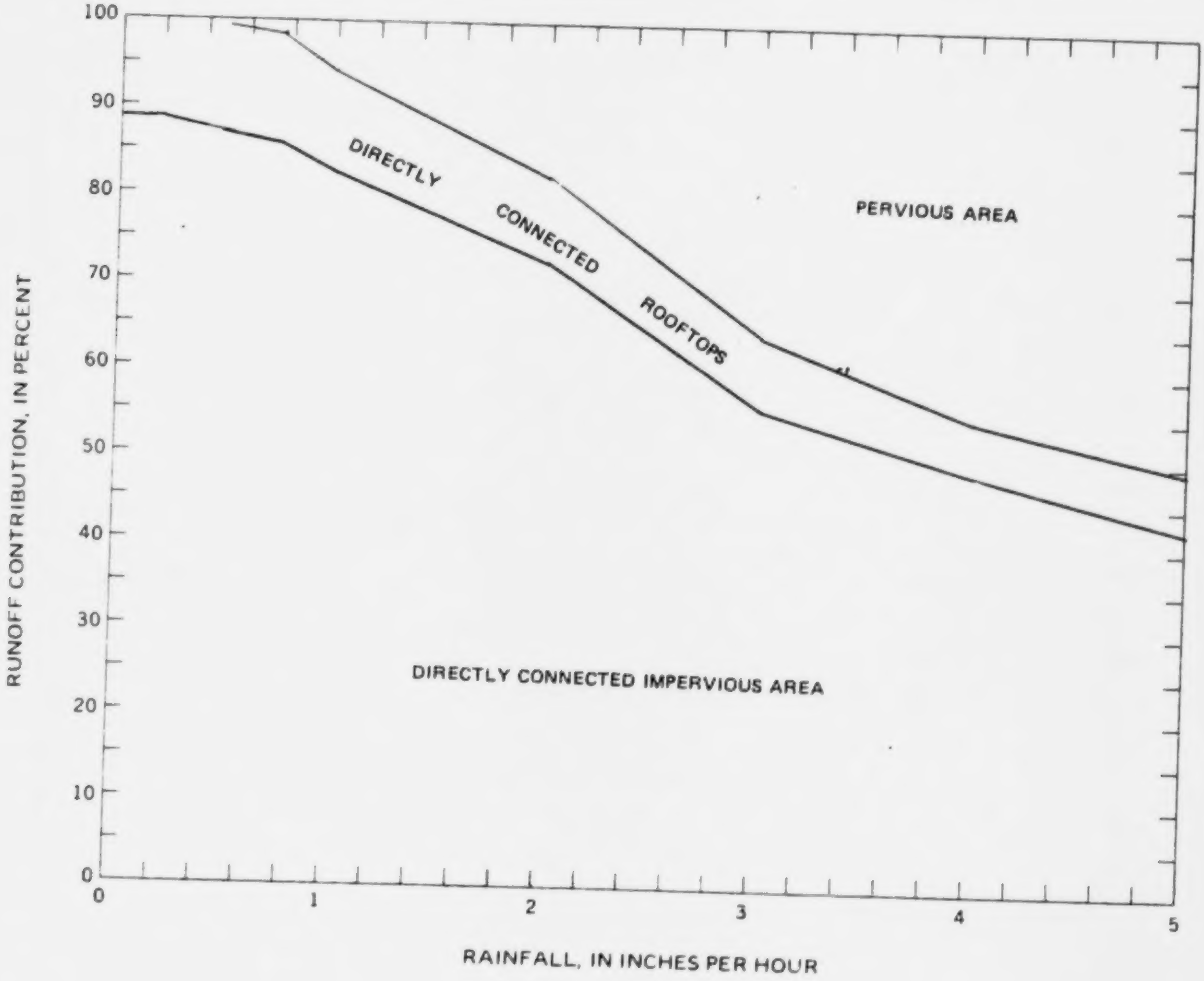


FIGURE III-6
SOURCES OF RUNOFF FOR HASTINGS STREET SITE (04087057) FOR 1 HOUR STORM DURATION

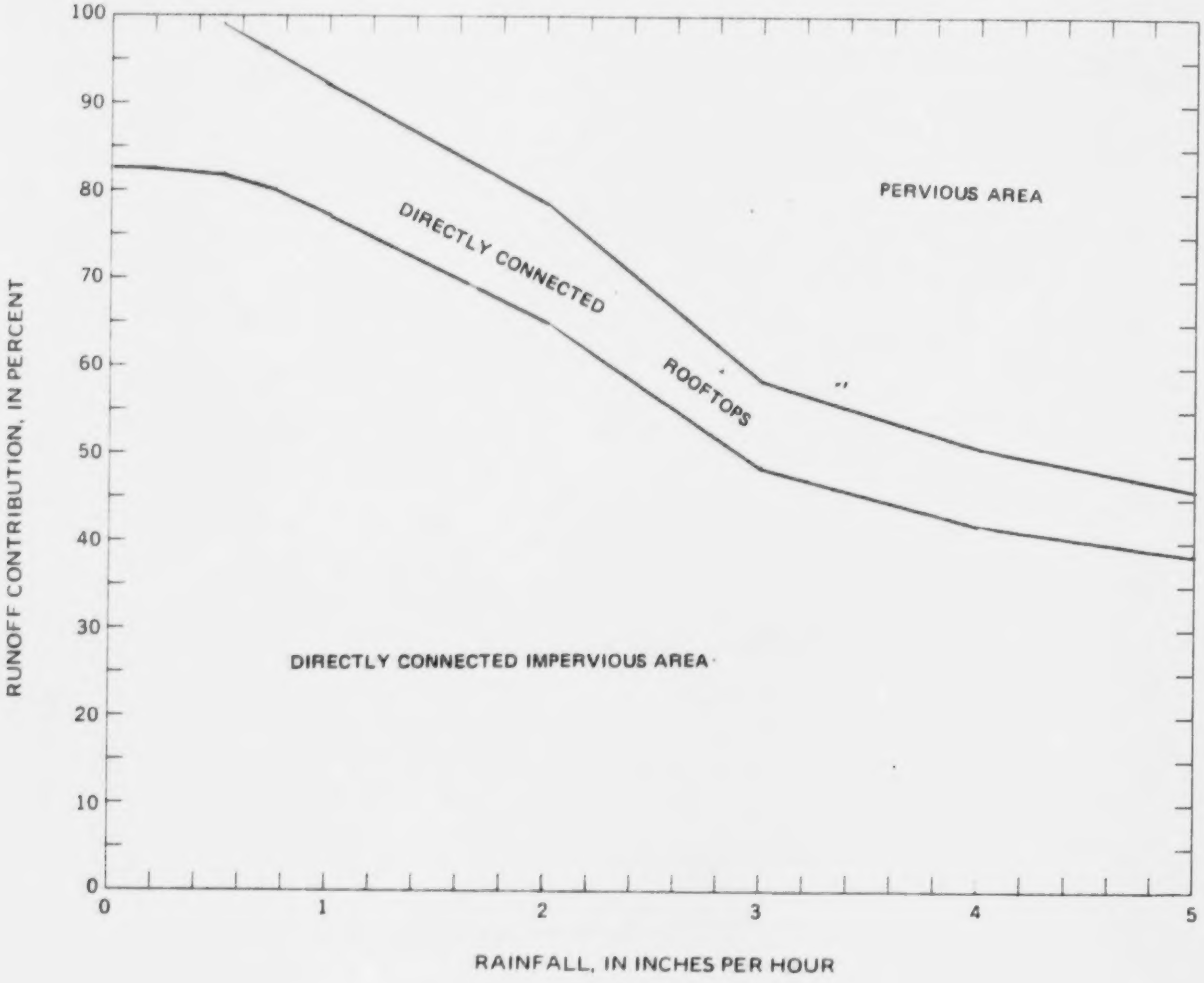


FIGURE III-7
SOURCES OF RUNOFF FOR PARK SITE (04087115) FOR STORMS OF 1 HOUR DURATION

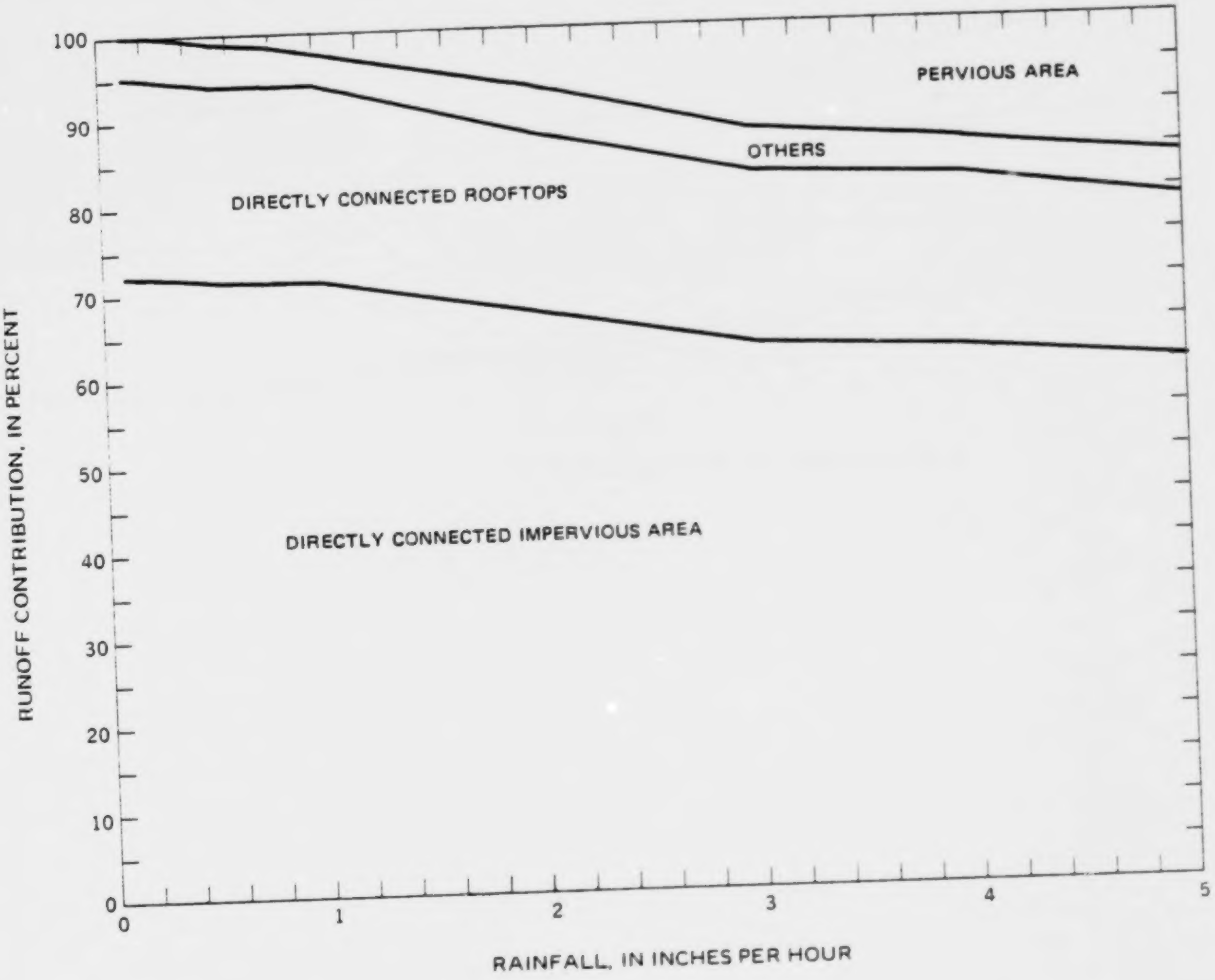
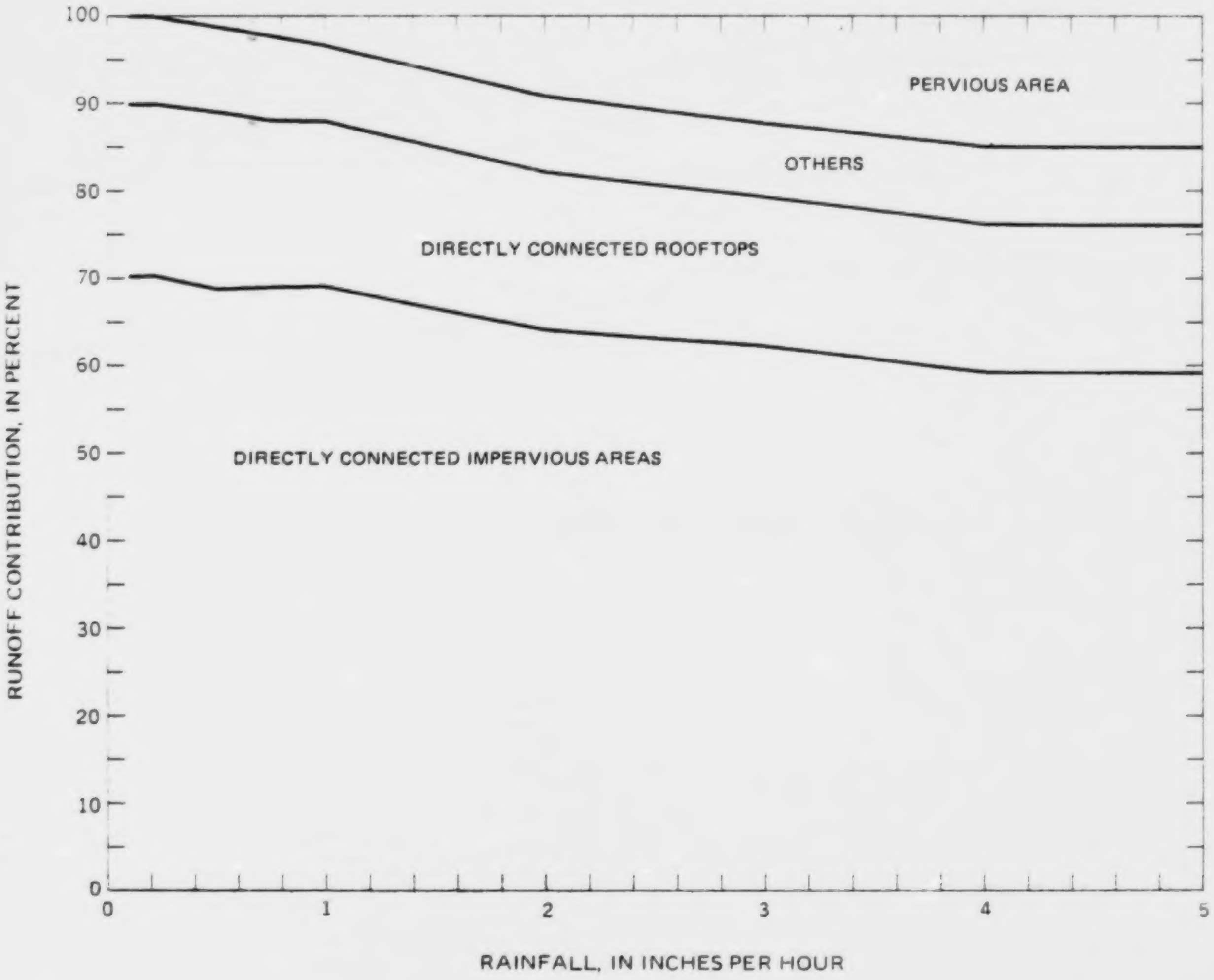


FIGURE III-8
SOURCES OF RUNOFF FOR WOOD CENTER SITE (04087133) FOR 1 HOUR STORM DURATIONS



rooftops are mostly drained to the lawns and when the infiltration capacity of the soil was exceeded the excess water drains to the street and is added to the runoff from the connected impervious surfaces.

USGS DISTRIBUTED ROUTING RAINFALL-RUNOFF MODEL

Data collected on the eight monitored sites was used to calibrate and verify the USGS Distributed Routing Rainfall-Runoff Model (DR3M) (Alley and Smith, 1982). The DR3M was used to compute the runoff volumes for sampled storm events for which the recording equipment malfunctioned or during periods when the flowmeters were not working properly and also to evaluate the sources of runoff within the monitored basins.

Description of the Model

The DR3M uses the kinematic wave theory to route flows overland and through a series of channels, either open or closed conduits. A soil-moisture accounting and infiltration procedure is used to determine the antecedent moisture condition. Rainfall excess from the previous areas along with the rain that falls on the hydraulically effective impervious areas (HEIA) is routed to the designed channels and through these channels to the basin outlet.

The basin can be divided into four types of segments--overland flow, channel or pipe, reservoir, or junction segments. For the basins monitored in the Milwaukee NURP Study, no reservoir segments were required. The model assumes that the overland flow drains uniformly laterally into the pipe segments.

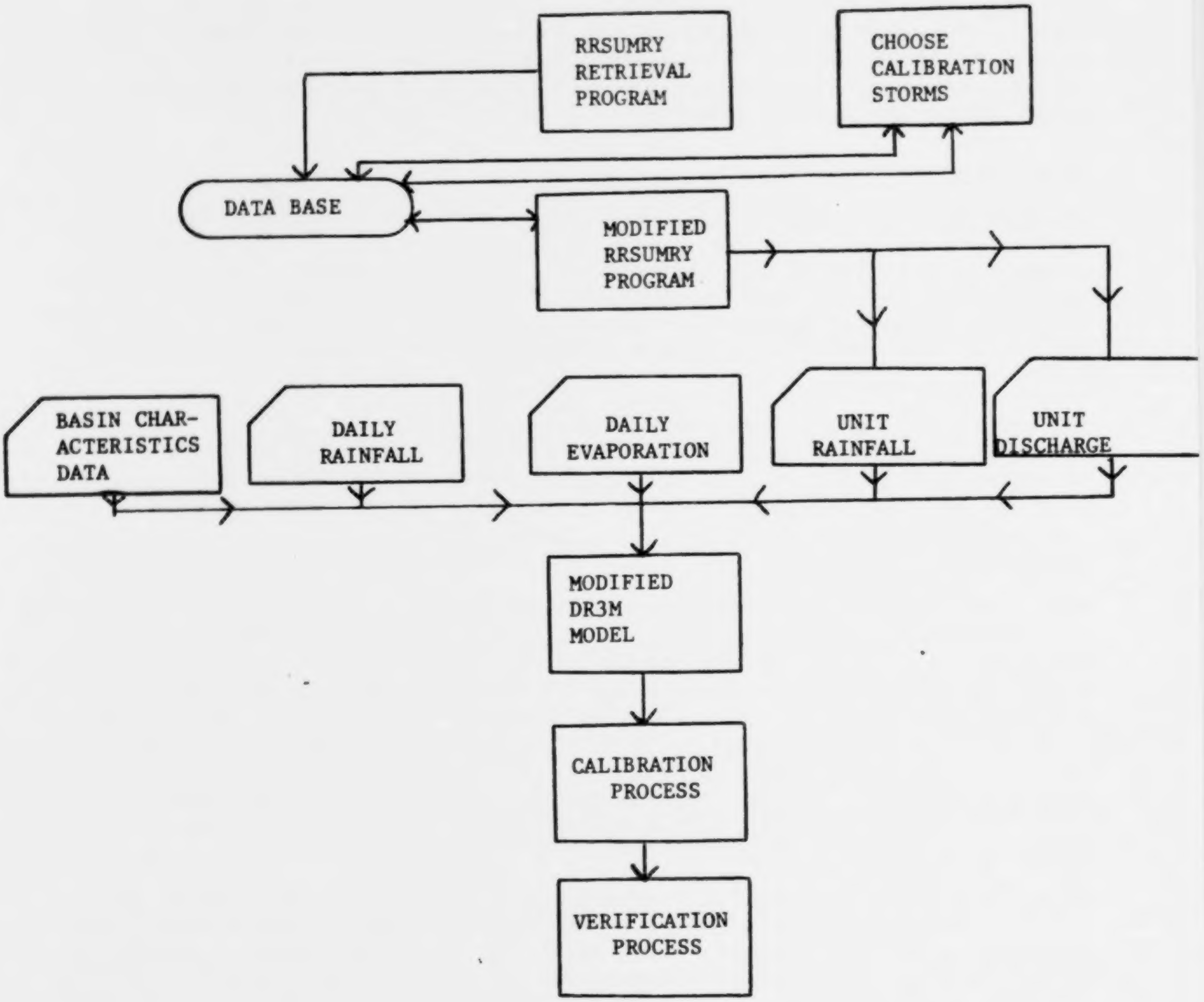
Data Inputs

All storm event rainfall and runoff data collected in this study were stored in the National Water Data Storage and Retrieval System (WATSTORE). A data management system designed by the USGS (Doyle and Lorens, 1982) was used to retrieve and process the rainfall and discharge records into the proper DR3M format. Figure III.9 presents a flow diagram for data processing and DR3M verification. Daily rainfall data from the U.S. Weather Bureau gage at Mitchell Field in Milwaukee (USWB, 1980, 1981, 1982) was used for the soil moisture accounting. Daily evaporation data were generated from a model which uses the Lamoreux (1962) formula with inputs of average daily temperature, dewpoint, total wind, and total solar radiation.

Basin characteristics data were determined by subdividing the drainage basins into overland and channel segments. SEWRPC supplied aerial photographs (scale 1"=100') with the external basin boundaries and the summary values of connected and unconnected impervious areas and rooftops, and the pervious area for each basin. Sewerage plans from the Milwaukee Engineering Department were used for the location and dimensions of the storm drainage system. These plans were also used to determine overland flow slopes and the slopes of the storm sewers. All basins were field checked to confirm the drainage boundaries and to determine roughness coefficients for overland and pipe flow.

FIGURE III-9

FLOW CHART FOR DR3M MODEL VERIFICATION


RRSUMRY RETRIEVAL PROGRAM
CHOOSE CALIBRATION STORMS
DATA BASE
MODIFIED RRSUMRY PROGRAM
BASIN CHARACTERISTICS DATA
DAILY RAINFALL
DAILY EVAPORATION
UNIT RAINFALL
UNIT DISCHARGE
MODIFIED DR3M MODEL
CALIBRATION PROCESS
VERIFICATION PROCESS

Calibration of the Model

Rainfall and runoff data monitored in 1982 were used to calibrate and verify the DR3M model. Data from 1982 provided the most accurate record due to final resolution of the proper depth sensing orifice to use with the Marsh-McBirney flowmeter (see discussion in Volume III). Calibration of the DR3M model consists of optimizing six parameters in the soil-moisture accounting and infiltration procedure. These parameters are as follows:

Soil-Moisture Accounting

Parameters	
EVC	A pan coefficient for converting measured pan evaporation to potential evaporation
RR	The proportion of daily rainfall that infiltrates into the soil for the period of simulation excluding unit days
BMSN	Available soil water at field capacity, in inches

Infiltration

Parameters	
KSAT	The effective saturated value of hydraulic conductivity, in inches per hour
RGF	Ratio of suction of the wetting front for soil moisture at wilting point to that at field capacity
PSP	Suction at wetting front for soil moisture at field capacity, in inches

An additional parameter, EAC, which is the hydraulically effective impervious area coefficient was the final value requiring optimization. The DR3M has a self-contained optimization routine which greatly simplifies the selection of the optimal values. One of the main inputs to the model is the amount of HEIA for each overland flow segment. During optimization of the EAC value, which should equal 1.0 if the proper HEIA was used, the only site with a significantly lower value of EAC was Lincoln Creek. This site was originally determined to have a HEIA of 44 percent, but from the calibration procedure was determined to be 30 percent. The remaining sites had acceptable values of EAC ranging from 0.95 to 1.01.

Verification of the Model

Data collected during 1982 was also used to verify the DR3M model. Earlier studies had developed the following standards for acceptance of the verification results (Doyle and Miller, 1980):

1. Hydrograph timing--peaks, rising and recession limbs within several minutes of observed data.
2. Hydrograph slope--basically the same as observed data.
3. Runoff volume--within 50 percent of measured values if simulated is less than measured and within 100 percent of measured if simulated is greater than measured.
4. Peak discharge--same criteria as stated for runoff volume.

Table III.8 lists some of the verification results for the eight sites. Observed and simulated runoff volumes and peak discharges with the corresponding percent error are shown. The storms used for verification at the Rustler, Post Office and Wood Center sites all met the acceptance criteria. These sites all had optimal monitoring conditions with straight pipes, uniform slopes, and no backwater problems. Some of the storms for the other sites had significant differences between the observed and simulated values. The West Congress, Hastings, and Burbank sites all had varying backwater conditions at the monitoring sites. This backwater condition had the effect of retarding the runoff from the basin and distorting the hydrograph shape. There was an occasional backwater problem at the Lincoln Creek site but not as significant as for the other three sites. The State Fair site had a small weir installed upstream of the flowmeter sensing head to make it possible to draw a sample with the automated sampler. This weir increased the turbulence near the sensing head which for certain flow rates resulted in incorrect recording of the flow.

Use of the USGS Distributed Routing Rainfall-Runoff Model

The USGS DR3M model was an invaluable tool for completing the missing record caused by monitoring instrument failure. Application of the model was most extensive for the 1981 monitoring period at the commercial and high density residential sites. During 1981 the depth sensing of the flowmeter for the commercial sites was adversely affected by turbulence created by the mounting hardware inside the storm sewer. Approximately 40 percent of the sampled events at the commercial sites during 1981 had volumes generated by the model. At the high density residential sites a recurring backwater condition from Lincoln Creek required simulation of approximately 35 percent of the events. At the parking lot and medium density sites the model was used to simulate volumes for those events when the recorders failed.

SUMMARY AND CONCLUSIONS

1. Storm-event rainfall and runoff volumes have been summarized for the years 1980-82 for the eight sites monitored as part of the Milwaukee Nationwide Urban Runoff Program.

2. Rainfall during 1980-82 was close to the 40-year normal with 1982 being slightly drier than 1980 and 1981.

3. The runoff coefficients (Rv) varied considerably between storms for each site but the mean Rv for the paired sites of each of the four land-use categories were very similar. Land use as reflected in the amount of connected impervious area was strongly correlated to the mean Rv value.

4. Regression equations which were developed to predict the runoff from observed rainfall had a high degree of correlation. These equations were used to compare the monitored runoff to the predicted runoff. The results indicate that most of the sites had about one-half or more of the runoff monitored and that the number of missed events due to equipment failure decreased with time.

5. The USGS Distributed Routing Rainfall Runoff Model was used to simulate the runoff volume for sampled events during which the digital recording equipment malfunctioned. The calibrated and verified model was then used to

TABLE III.8

DR3M MODEL VERIFICATION RESULTS

Storm date	Rainfall (cm)	Observed runoff (cm)	Simulated runoff (cm)	Percent error	Observed peak Q (m^3/s)	Simulated peak Q (m^3/s)	Percent error
Commercial							
State Fair							
4- 2-82	0.34	0.48	0.96	+98	0.06	0.22	+232
5-15-82	0.38	0.10	0.14	+38	0.23	0.20	-13
5-18-82	0.13	0.14	0.03	-7	0.04	0.03	-30
6-20-82	0.38	0.12	0.12	-2	0.34	0.18	-48
6-25-82	0 33	0.10	0.09	-8	0.25	0.15	-39
Wood Center							
4- 2-82	2.69	1.97	2.53	28	0.42	0.41	-2
4-16-82	1.62	1.02	1.44	42	1.25	1.10	-12
4-16-82	0.30	0.24	0.23	-2	0.20	0.19	-4
5-27-82	0.30	0.21	0.26	+20	0.24	0.22	-4
6-15-82	2.26	1.59	2.01	+26	0.42	0.50	+17
Parking Lot							
Rustler							
4- 2-82	0.79	0.56	0.60	-7	0.06	0.04	-20
4- 2-82	2.06	2.11	2.01	-4	0.08	0.10	+18
4- 3-82	1.91	1.67	1.85	+11	0.14	0.18	+28
5-26-82	0.53	0.43	0.39	-10	0.06	0.05	-19
6-25-82	0.84	0.65	0.68	+5	0.08	0.06	-24
Post Office							
4- 2-82	0.71	0.59	0.64	+9	0.07	0.08	+14
4- 2-82	2.44	2.16	2.36	+9	0.14	0.19	+43
5-11-82	1.19	1.10	0.83	-24	0.51	0.42	-17
5-22-82	1.24	0.89	1.14	+28	0.06	0.11	+65
6-15-82	1.88	1.85	1.81	-2	0.11	0.11	+3
High Density Residential							
Lincoln Creek							
4- 2-82	0.79	0.16	0.19	+19	0.06	0.08	+26
4- 2-82	1.02	0.27	0.29	+8	0.13	0.12	-4
5-11-82	1.22	0.30	0.36	+25	0.45	0.13	-70
6- 7-82	0.48	0.11	0.10	-13	0.20	0.16	-21
6-15-82	2.00	0.46	0.64	+37	0.09	0.11	+25
West Congress							
4- 2-82	0.74	0.10	0.22	+123	0.05	0.08	+48
4- 2-82	2.10	0.32	0.87	+170	0.10	0.21	+114
5-15-82	0.30	0.06	0.05	-24	0.15	0.05	-63
5-27-82	0.36	0.03	0.08	+153	0.02	0.02	+21
6-20-82	0.30	0.02	0.07	+170	0.03	0.04	+32
Medium Density Residential							
Hastings							
4- 2-82	2.26	0.90	0.78	-14	0.20	0.17	-16
5-11-82	2.11	0.47	0.72	+52	0.62	0.66	+6
5-22-82	0.64	0.13	0.18	+43	0.05	0.06	+26
5-26-82	0.64	0.11	0.19	+62	0.06	0.10	+53
6-15-82	1.98	0.22	0.68	+200	0.10	0.12	+25
Burbank							
4-16-82	0.76	0.20	0.22	+8	0.37	0.27	-24
5-11-82	2.08	0.75	0.69	-8	0.99	1.25	+26

estimate the relative importance of different sources of runoff for each site. The resulting analysis indicates that for storms with a duration of 1 hour and accumulations of up to 1 in. there will be a relatively small amount of total runoff volume coming from the pervious areas.

CHAPTER IV.

CHARACTERIZATION OF URBAN STORMWATER

INTRODUCTION

The objective of this chapter is to describe the characteristics of stormwater draining established urban land uses in Milwaukee County, Wisconsin. The characteristics presented in this chapter were selected to assist in the development of a nonpoint source pollution control program for an urbanized watershed. The first parts of the chapter will describe the levels and types of stormwater pollutants expected in established urban areas by using the event mean concentration, flow weighted concentrations and annual event loading value determined at the study areas. The last part of the chapter uses the monitoring results from other water quality studies in Milwaukee County to assess the impact of urban stormwater on water quality. The concentration and loading values measured at the study areas might vary somewhat for the same type of urban land uses in other locations, but the results described in the chapter will help characterize the importance of urban runoff in all Wisconsin watersheds.

The most critical land uses in a watershed should be identified during the development of nonpoint source management strategy and would receive higher priority for the implementation of management practices. The first part of this chapter Chapter IV uses the mean event concentration, flow weighted concentration and unit loading values to rank the urban land uses represented by the study areas. The importance of established urban land uses in a watershed was further characterized by comparing their pollutant levels with those observed at adjacent urbanized drainage areas and selected Wisconsin agricultural drainage areas. The comparisons of pollutant levels also served to characterize the types of pollutants that are important in urban and agricultural areas.

Pollutant loading values at the study areas and other single land use drainage areas monitored in Milwaukee County were used to determine normalized annual event unit area loading values for all the major established urban land uses. The urban land uses were ranked using the normalized unit area loading values. The most useful role of the unit area loading values would be the determination of annual event pollutant loading values for each land use in an urban area. The problems associated with extrapolating the loading values were evaluated and the normalized unit area loading values were used to estimate annual pollutant loading values in three urban subwatersheds of the Menomonee River watershed.

The first parts of the chapter also include an evaluation the seasonal trends in the event mean concentrations and the differences between paired sites. The EPA proposed acute toxicity criteria was used to help identify the important metals in urban runoff.

Although evaluating the impact of urban runoff on receiving waters was not a part of this project, it would have been inappropriate to ignore any available data that could help assess the impact of urban runoff in the streams adjacent to the study areas. The Menomonee River Watershed is adjacent to the study areas and concern about the water quality in the watershed has prompted a number of monitoring studies. The last part of Chapter IV uses the results of the previous studies to evaluate changes in water quality from the rural to urbanized reaches of the Menomonee River. The results include data from fish and macroinvertebrate surveys, analysis of bottom sediments and flow weighted average event concentrations in the river.

DESCRIPTION OF THE STORMWATER MONITORING PROGRAM

Automatic monitoring equipment was used to collect runoff samples and measure flow in stormsewers draining eight study areas. The study areas were selected to characterize the stormwater quality for four predominant types of established urban land uses. A pair of adjacent study areas represented each type of land use. The four types of land uses were commercial, parking lot, high density residential and medium density residential. The study areas ranged in size from about 5 to 25 hectares (12 to 63 acres) and all the necessary inventory information for each study area is discussed in Chapter 2, Volume III. The water quality data from one of the high density residential sites (Congress) was not used to characterize urban stormwater because backwater conditions in the stormsewer caused inaccurate flow measurements and low pollutant concentration due to the settling of particulates. Only the other seven study areas will be discussed in the rest of this chapter.

The goal of the water quality monitoring program was to obtain a composite water sample at each study area for every runoff event during the period March 1980 to June 1982. By the end of the monitoring period a total of 415 composite samples had been collected from the seven study areas and the number of composite samples collected at each study area is listed below.

Study Area	Land Use	Number Composite Samples
State Fair	Commercial	51
Wood Center	Commercial	66
Rustler	Parking Lot	70
Post Office	Parking Lot	82
Lincoln Creek	High Density Residential	39
Hastings	Medium Density Residential	47
Burbank	Medium Density Residential	52

The number of events sampled at most study areas represented about one half of all the runoff events that occurred during the monitoring period. Failures in the automatic monitoring equipment accounted for most of the missing samples.

The composite samples were composed of discrete samples collected flow proportionally by a Manning S-4050 sequential water quality sampler. A flow proportional contact closure switch on the Marsh - McBirney Model 250 flow meter activated the water sampler after a pre-set volume of runoff had passed the monitoring point in the stormsewer. A pre-set volume was selected to collect enough samples to characterize the variability in the concentration for small events and to limit the possibility of a large event exceeding the bottle capacity of the sampler. The sampler was set to put two samples in each one liter bottle. Each sampling station also contained a recording rain gauge which activated the flow meter after 0.01 inches of rainfall had accumulated.

At the end of a runoff event the discrete samples were immediately collected from the refrigerated water sampler and brought to a field office. The flow proportional sampling method made it possible to directly composite the discrete samples in a DECA sample splitter. The one liter composite samples were further split into four aliquots for preservation and shipment to the laboratory for analysis. Analysis of the composite sample determined the mean event concentration for at least seven parameters in every sampled runoff event. The parameter list included primary, secondary and the less frequently analyzed parameter. The primary list was analyzed for every event and included total solids, suspended solids, suspended volatile solids, total lead, chloride, total P and soluble P. The secondary parameters were analyzed for many of the events and included the nitrogen series, 5-Day BOD, dissolved lead and COD. The less frequently analyzed parameters required a larger volume of water and included 30 Day BOD, particle size and multi-element scans. The samples for fecal coliform counts were collected by grab samples and they were not composited.

A more detailed description of the sampling procedures and equipment is discussed in Chapter 3 of Volume III.

CHARACTERISTICS OF EVENT MEAN CONCENTRATIONS

Analysis of the distribution of event mean concentrations in urban stormwater revealed that these concentrations are not normally distributed, but are instead skewed towards low concentrations. By transforming the concentrations to their natural logs, normally distributed populations were obtained. The probability functions presented in this report were derived using log transformed data.

Those stations at which more samples were taken exert more influence in the computation or probability functions for aggregated stations, such as specific paired stations or all land uses combined. This imbalance in sampling results in a bias in the land use probability functions towards those stations or land uses with more samples. These biases should be considered when comparing computations from different land uses from paired stations of a given land use. Additional sources of variability in the probability functions include the differences in sampling periods for different stations, and inherent differences in the individual events samples, as different events were sampled at different stations.

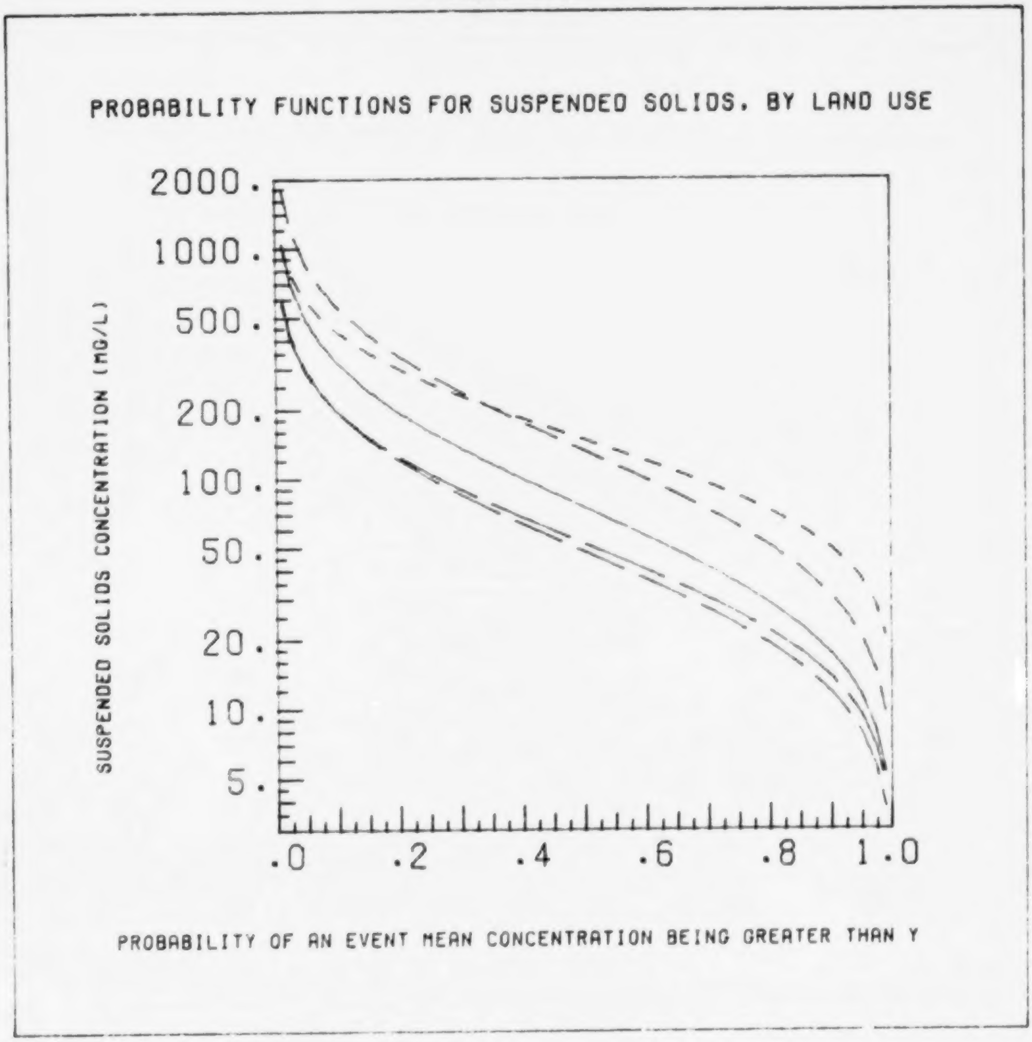
Figures IV. 1-14 present probability functions plotted by land use for the primary and secondary parameters. The pollutants represented on the first five figures are suspended solids, total phosphorus, five day BOD, total lead and total zinc. These pollutants were chosen as having characteristics representative of the results observed for the other pollutants and the discussion in this section of Chapter IV focuses on these pollutants.

The probability functions plotted in Figures IV. 1-5 indicate the probability of a mean concentration being equaled or exceeded during an event. For example, a probability of .5, 50 percent (the median) of all event mean concentrations were above the corresponding Y axis concentration, and of course, 50 percent were below it. Similarly, a .1 probability indicates that 10 percent of the events were above the corresponding Y axis concentration, and 90 percent were below it. Therefore, for a given concentration (within the range of the Y axis), the probability of an event mean concentration exceeding that value can be estimated. Whereas these graphs indicate the overall probabilities of a concentration being equaled or exceeded, they do not indicate under what conditions that is likely to occur. For example, it would be useful to be able to associate probability plots with the characteristics of the rainfall. However, a statistical analysis of the data did not find a significant relationship between event mean concentrations and rainfall characteristics.

For suspended solids, the plots indicated that most often the commercial study areas have the highest event mean concentration, but the line for the high density residential area was very close. The medium density residential and parking lot study areas shared similar concentrations that were much lower than the other areas. The relationships between suspended solids concentrations and impairment of beneficial use is not very well understood. Except for long term exposure at high concentrations, the primary effect in aquatic organism is probably indirect. For example, the higher mean event concentration observed at the commercial study areas might cause some damage to the stream habitat due to deposition of solids, especially in reaches of the receiving stream with lower flow velocities.

The high density residential areas had much higher concentrations of total phosphorus than the other land uses. The commercial areas had the next highest concentration, followed closely by the medium density residential. Parking lots generate much lower concentrations of total phosphorus concentrations than the other areas. The higher total phosphorus concentrations in the high density residential areas were probably caused by the deposition of larger amounts of vegetative litter. The streets in the high density residential area were lined with large maple trees and the alley ways are lined with trees and bushes. The volatile suspended solids concentrations were also highest for the high density residential area which suggests the stormwater contained larger amounts of organic matter. The parking lots and commercial areas had a limited amount of vegetation and the trees were further apart and much smaller in the medium density residential areas.

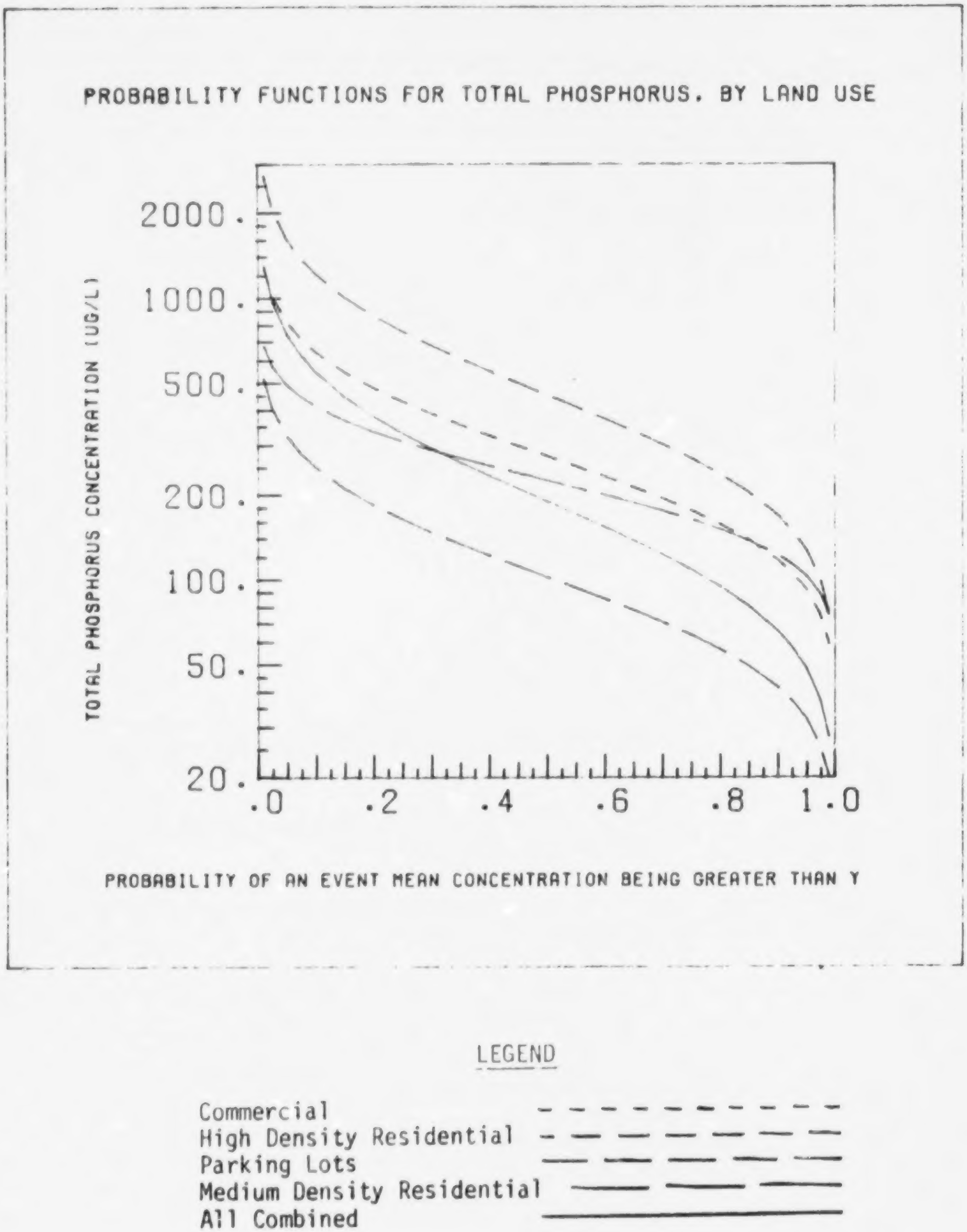
FIGURE IV.1



LEGEND

Commercial - - - - - - - - -
High Density Residential – — — — — — —
Parking Lots —— —— —— —— ——
Medium Density Residential ——— ——— ———
All Combined ————————

FIGURE IV.2



PROBABILITY FUNCTIONS FOR TOTAL PHOSPHORUS. BY LAND USE

FIGURE IV.3

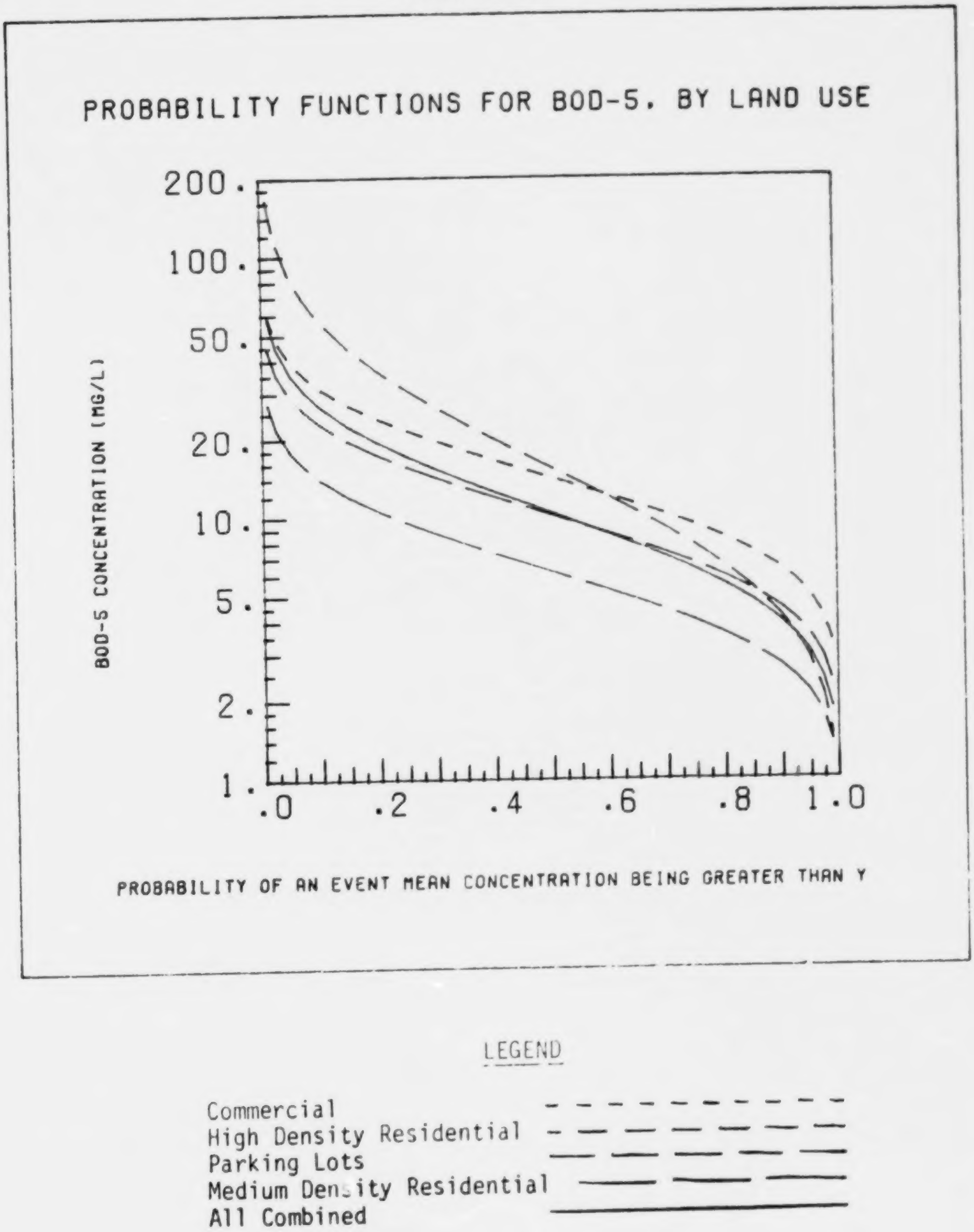

PROBABILITY FUNCTIONS FOR BOD-5, BY LAND USE
BOD-5 CONCENTRATION (MG/L)
200.
100.
50.
20.
10.
5.
2.
1.
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

FIGURE IV.4

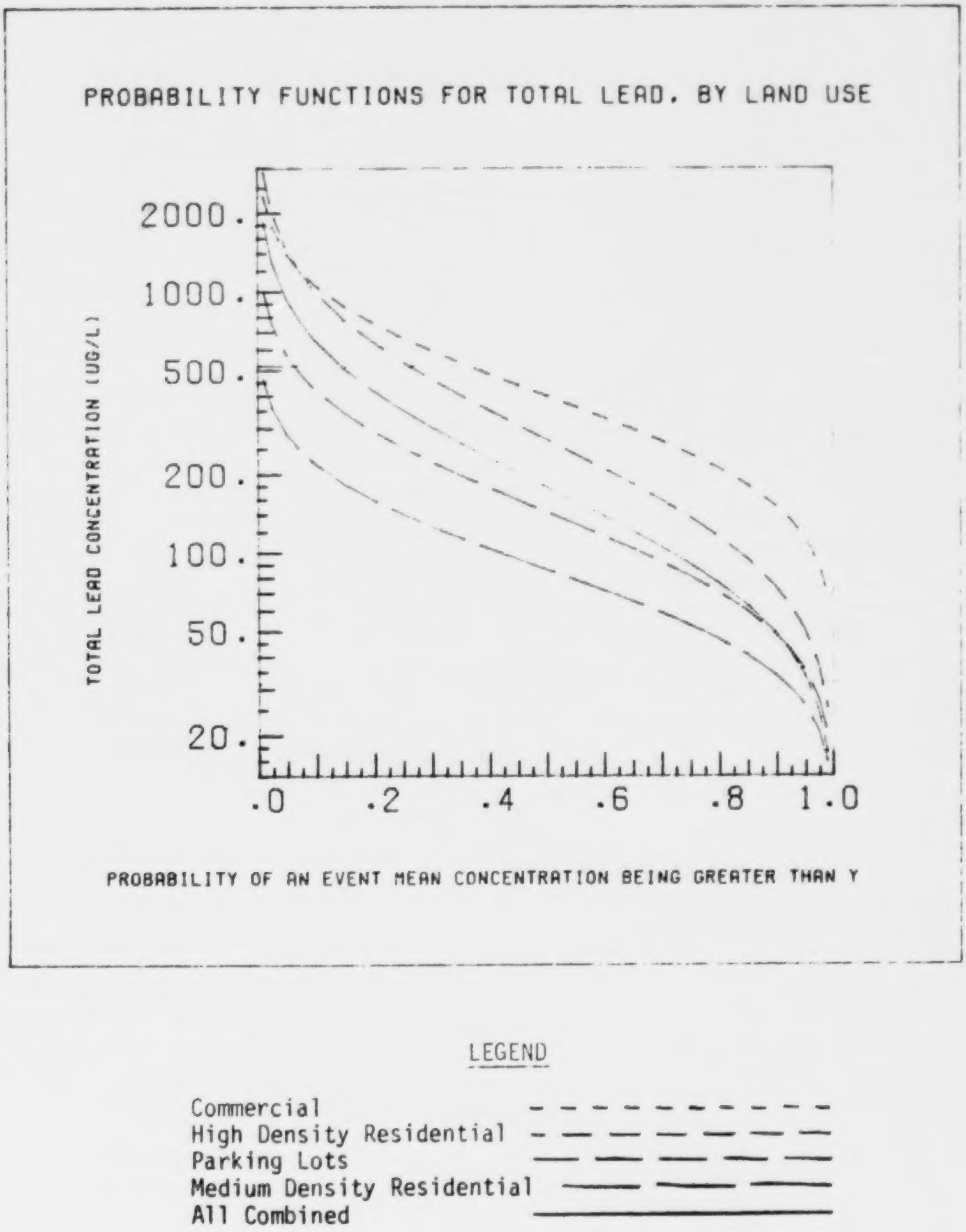
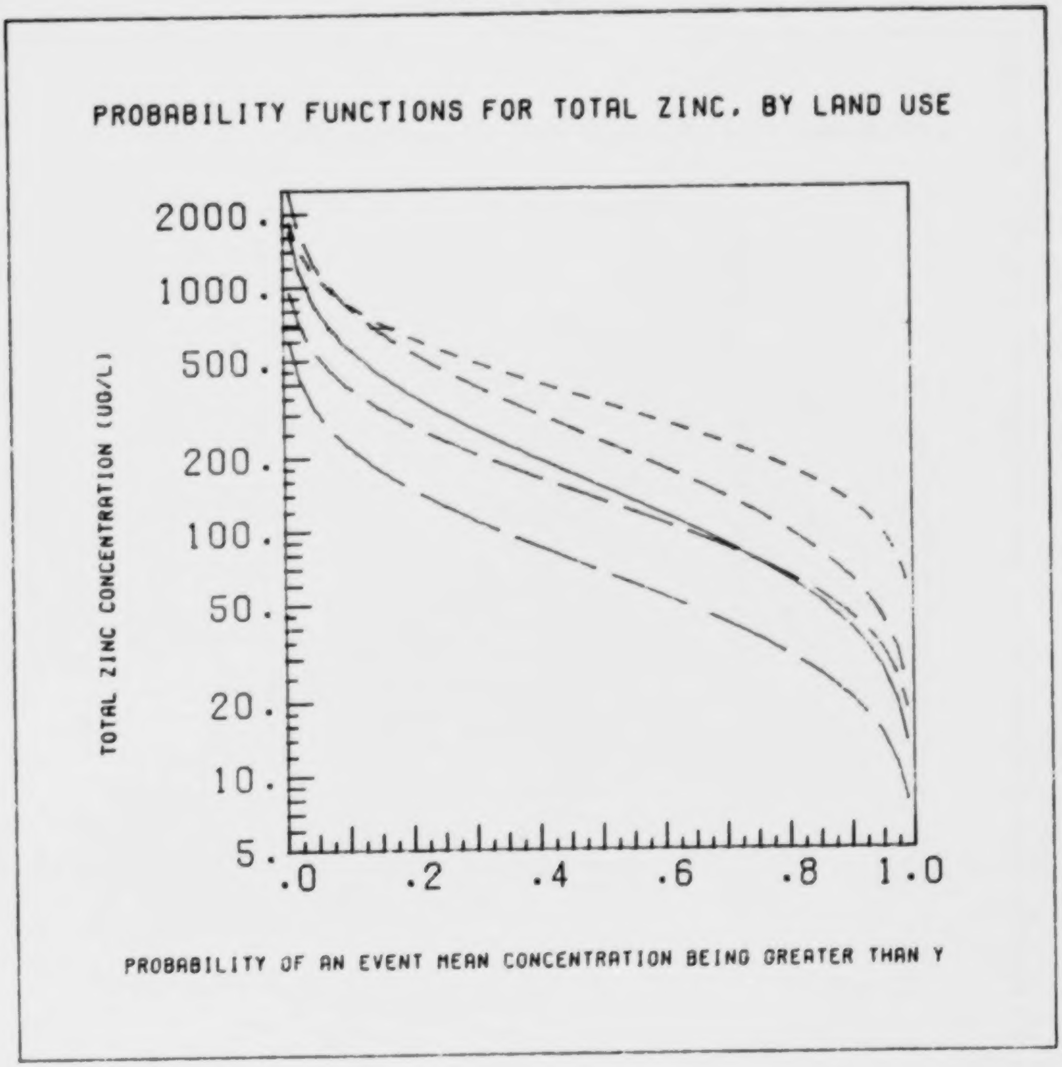

PROBABILITY FUNCTIONS FOR TOTAL LEAD, BY LAND USE
TOTAL LEAD CONCENTRATION (UG/L)
2000.
1000.
500.
200.
100.
50.
20.
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

FIGURE IV.5



LEGEND

Commercial	- - - - - - - - - -
High Density Residential	– — — — — — —
Parking Lots	—— —— —— —— ——
Medium Density Residential	——— ——— ———
All Combined	————————————

FIGURE IV.6

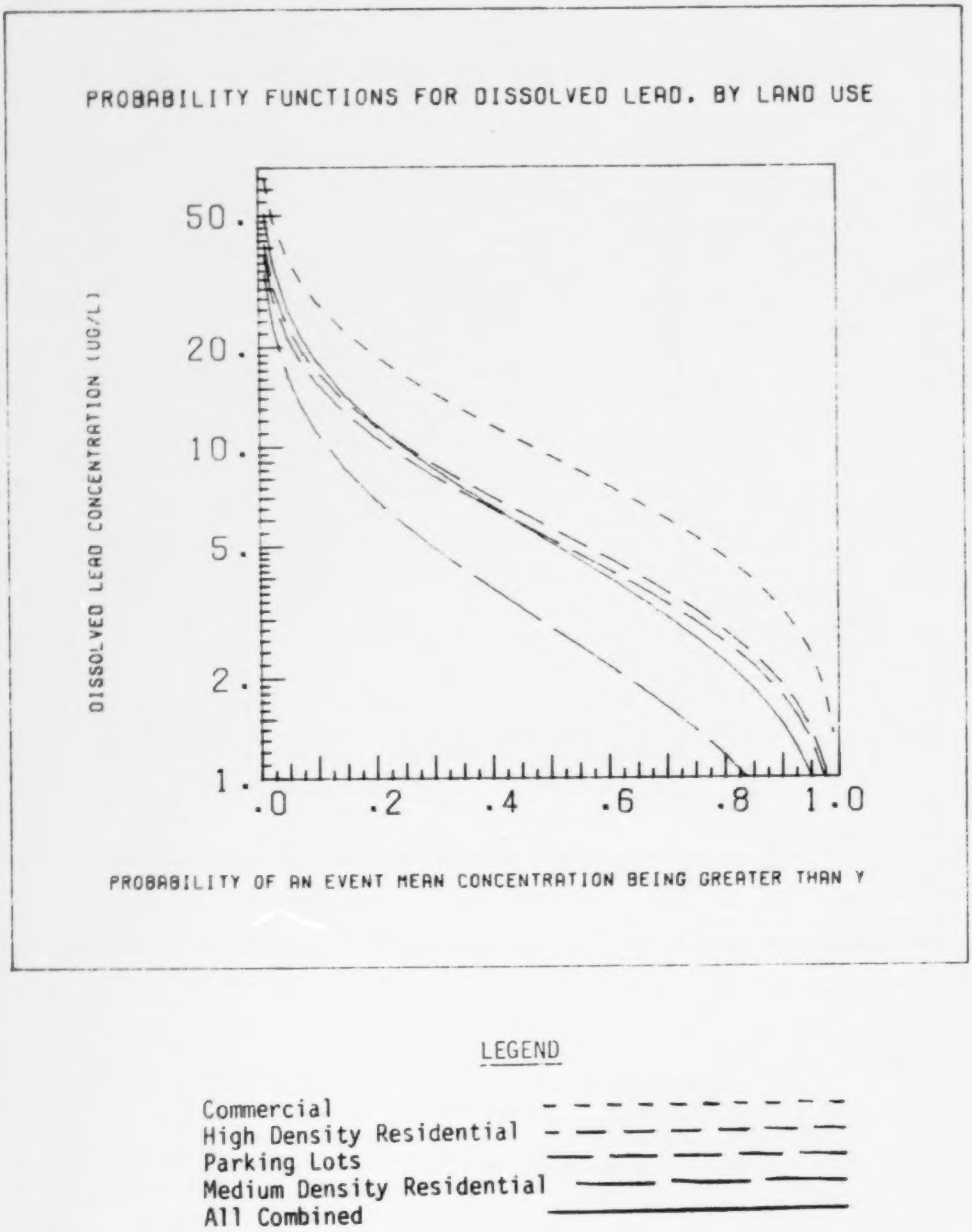

PROBABILITY FUNCTIONS FOR DISSOLVED LEAD, BY LAND USE
DISSOLVED LEAD CONCENTRATION (UG/L)
50.
20.
10.
5.
2.
1.
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

FIGURE IV.7

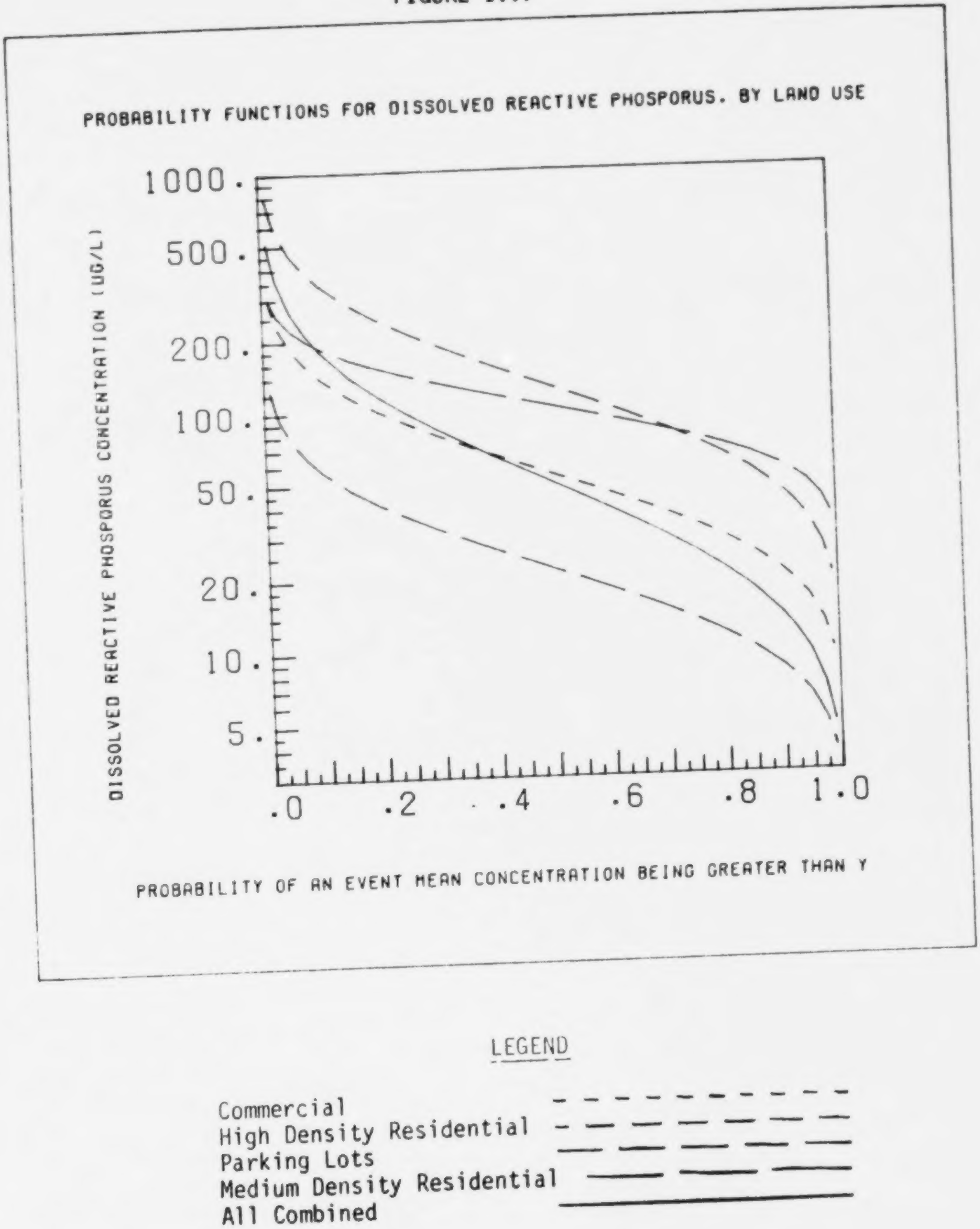

PROBABILITY FUNCTIONS FOR DISSOLVED REACTIVE PHOSPORUS. BY LAND USE
DISSOLVED REACTIVE PHOSPORUS CONCENTRATION (UG/L)
1000.
500.
200.
100.
50.
20.
10.
5.
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

FIGURE IV.8

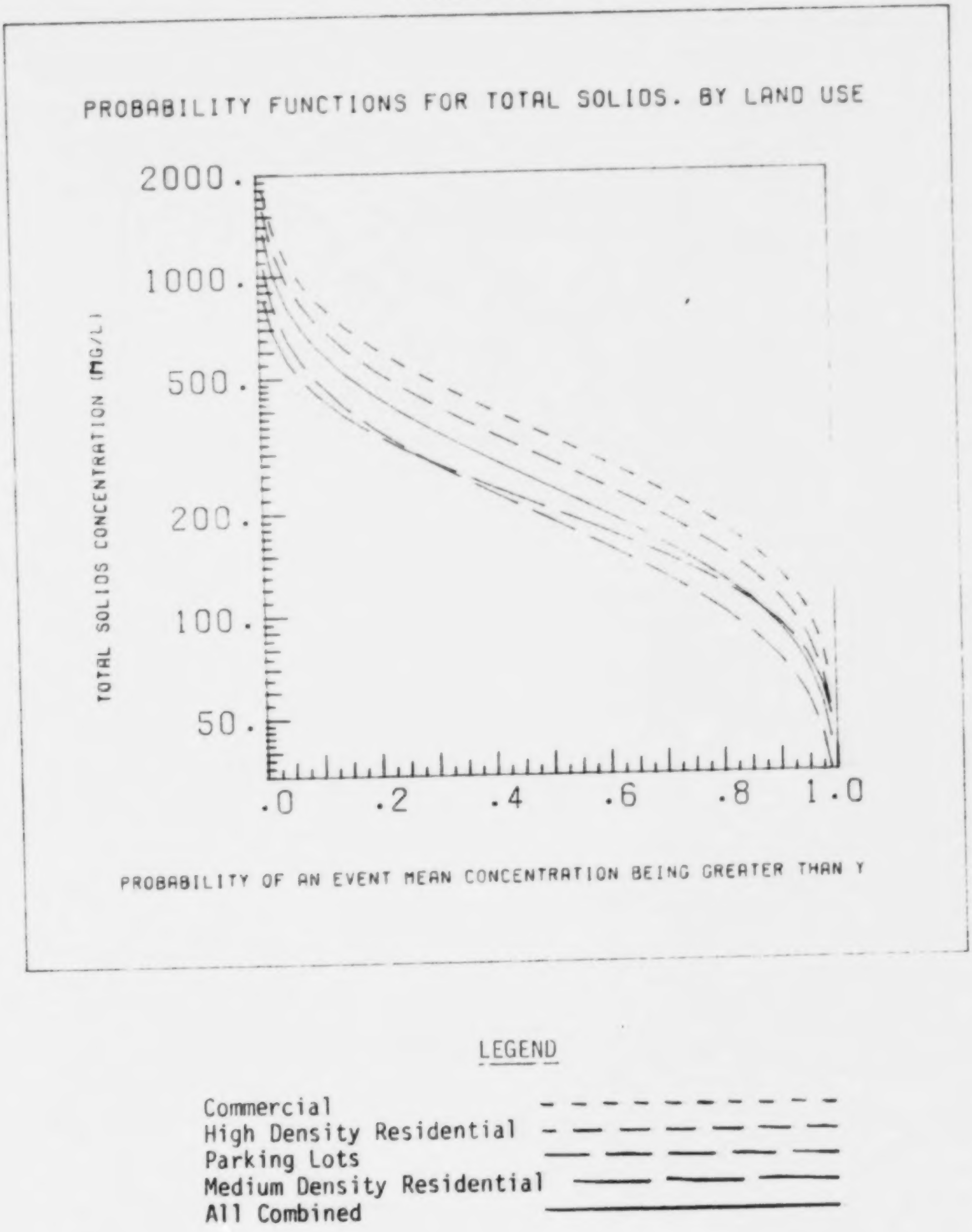

PROBABILITY FUNCTIONS FOR TOTAL SOLIDS. BY LAND USE
TOTAL SOLIDS CONCENTRATION (MG/L)
2000
1000
500
200
100
50
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

FIGURE IV.9

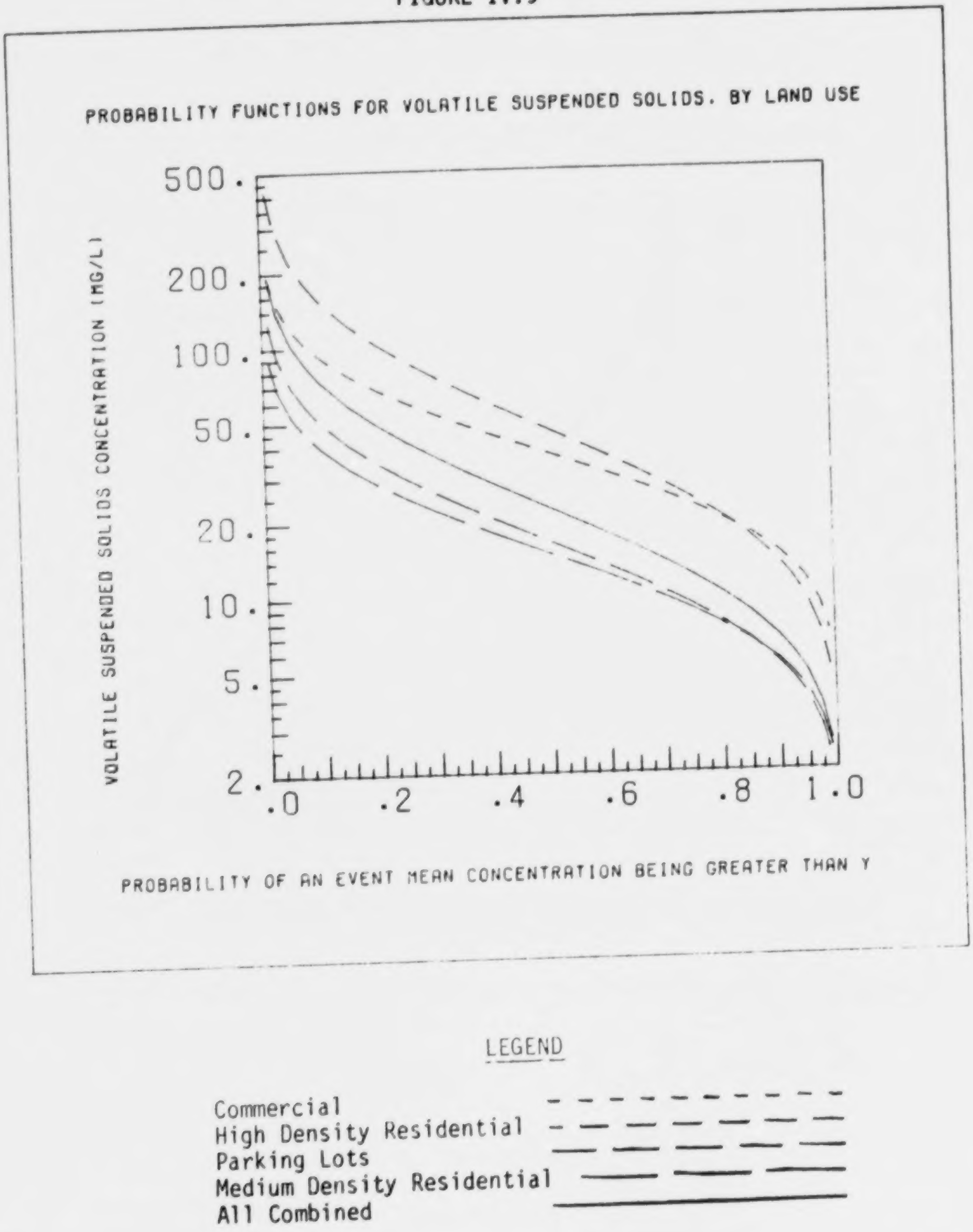

PROBABILITY FUNCTIONS FOR VOLATILE SUSPENDED SOLIDS. BY LAND USE
VOLATILE SUSPENDED SOLIDS CONCENTRATION (MG/L)
500.
200.
100.
50.
20.
10.
5.
2.
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

FIGURE IV.10

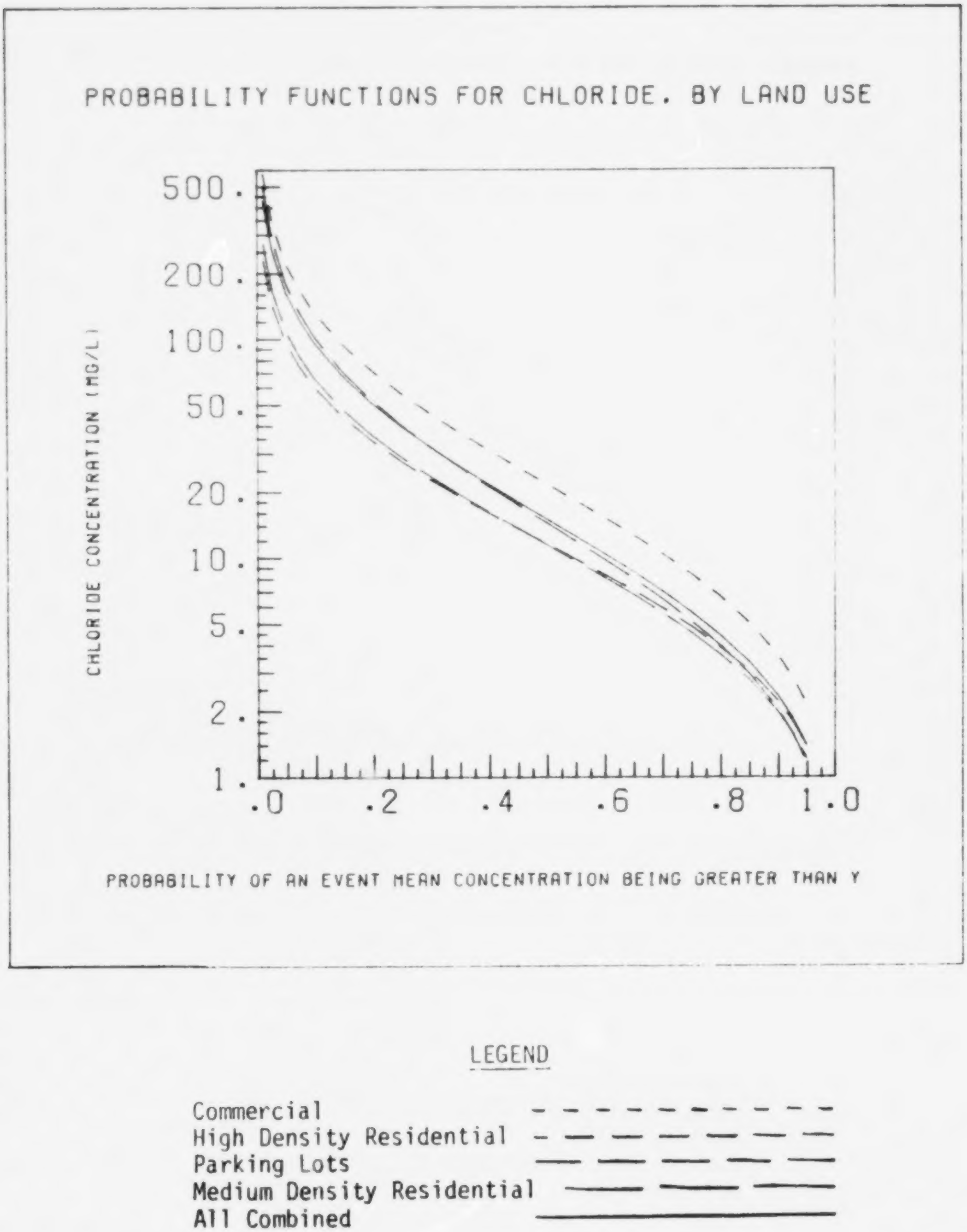

PROBABILITY FUNCTIONS FOR CHLORIDE. BY LAND USE
CHLORIDE CONCENTRATION (MG/L)
500.
200.
100.
50.
20.
10.
5.
2.
1.
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

FIGURE IV.11

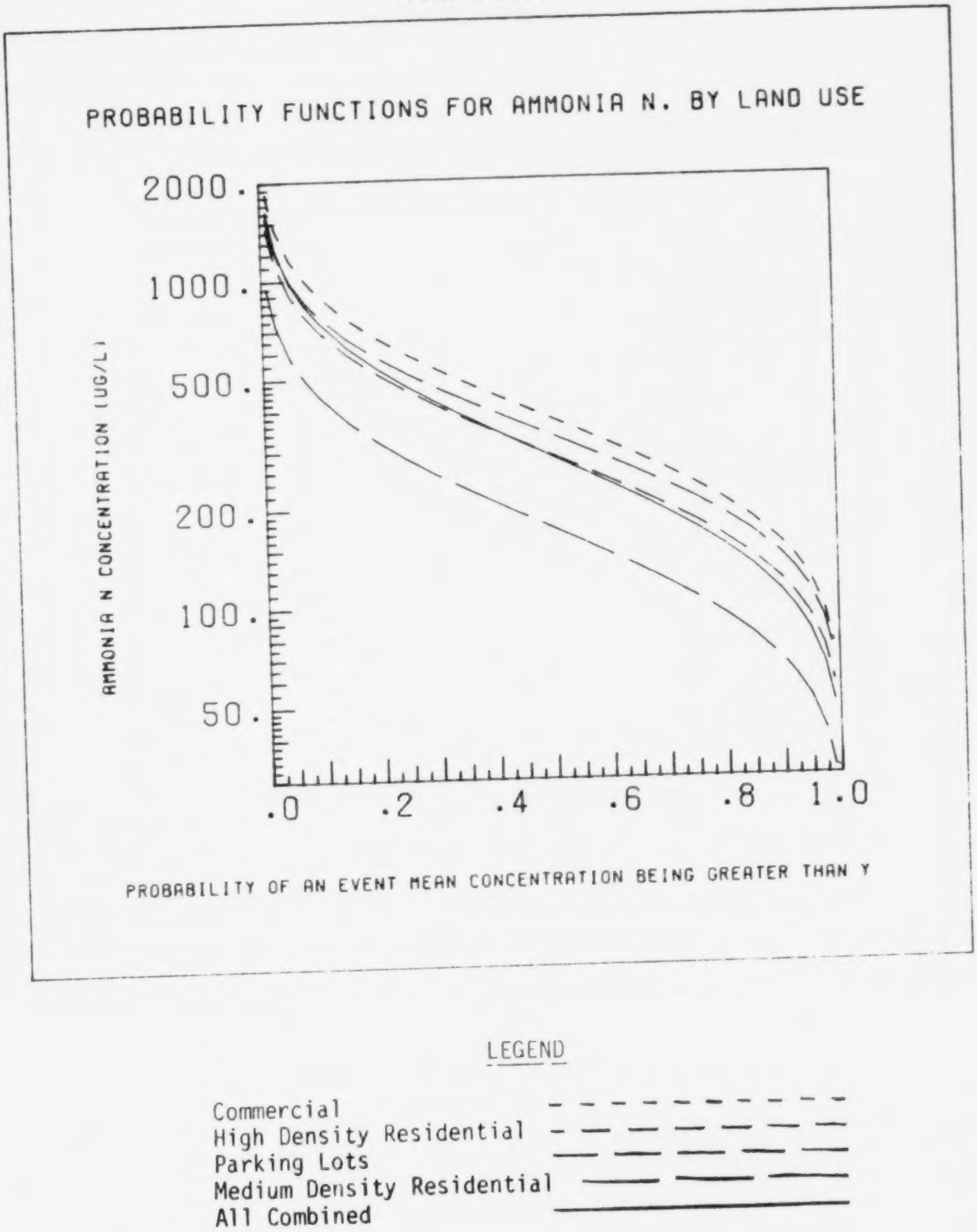

PROBABILITY FUNCTIONS FOR AMMONIA N. BY LAND USE
AMMONIA N CONCENTRATION (UG/L)
2000
1000
500
200
100
50
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

FIGURE IV.12

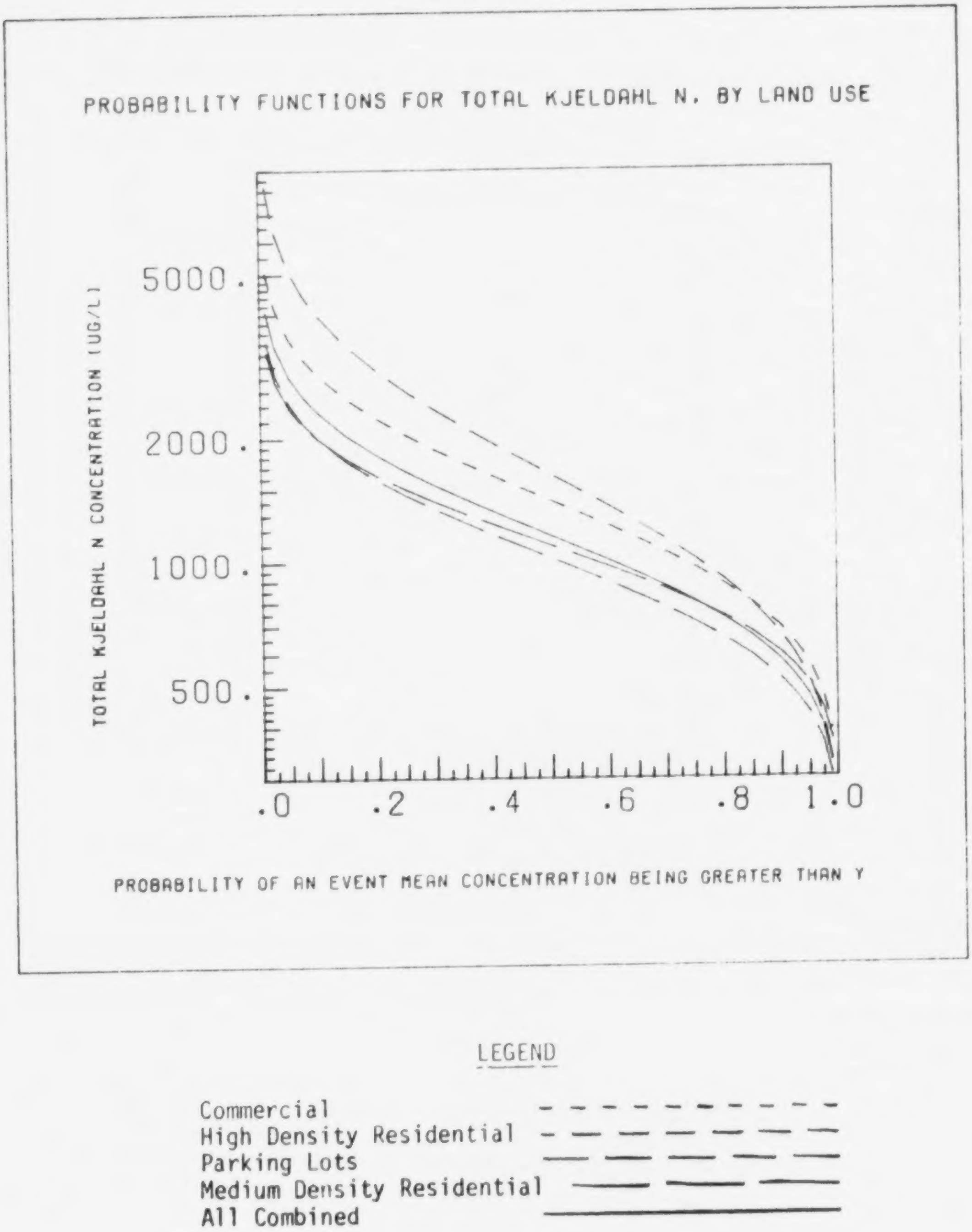
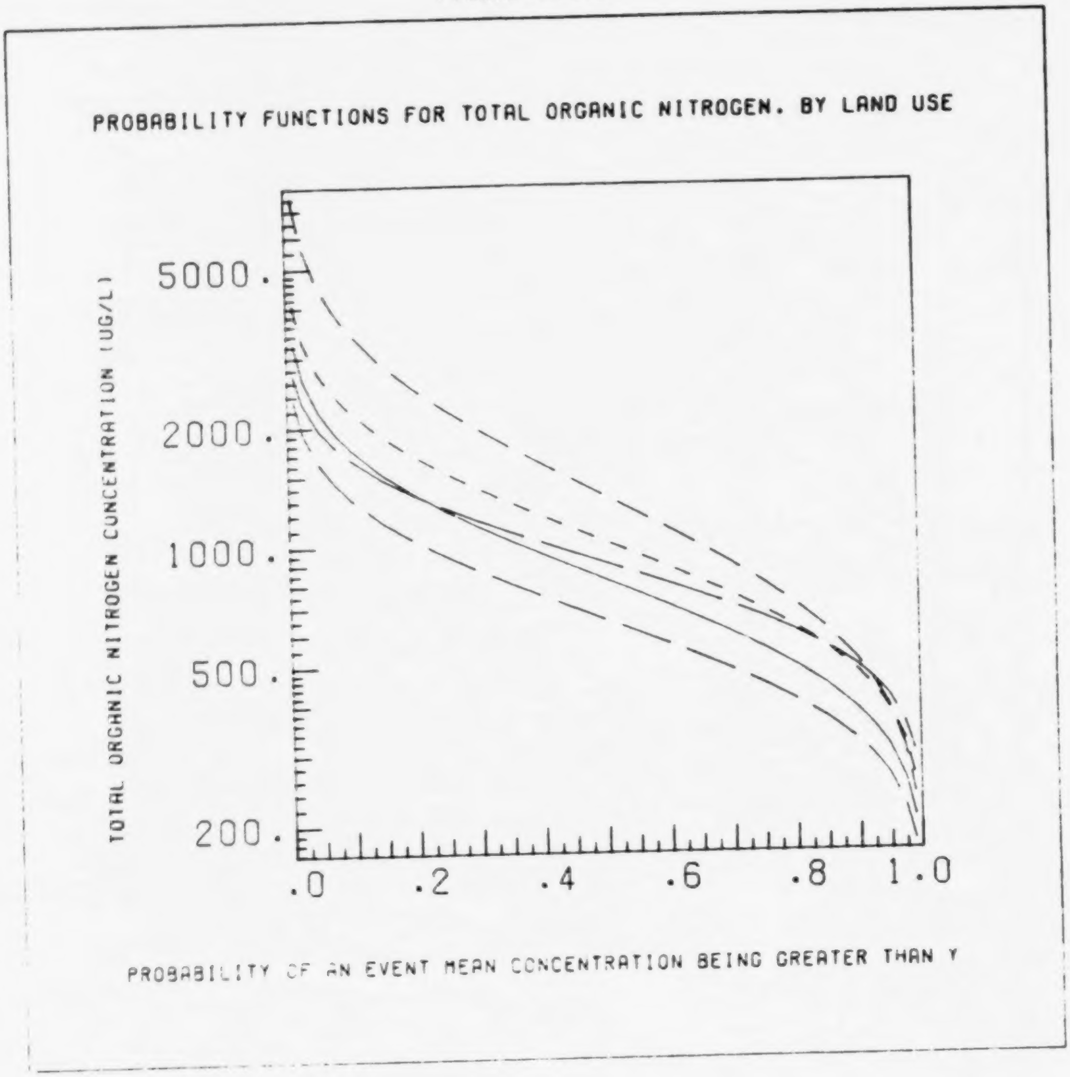

PROBABILITY FUNCTIONS FOR TOTAL KJELDAHL N. BY LAND USE
TOTAL KJELDAHL N CONCENTRATION (UG/L)
5000.
2000.
1000.
500.
.0
.2
.4
.6
.8
1.0
PROBABILITY OF AN EVENT MEAN CONCENTRATION BEING GREATER THAN Y
LEGEND
Commercial
High Density Residential
Parking Lots
Medium Density Residential
All Combined

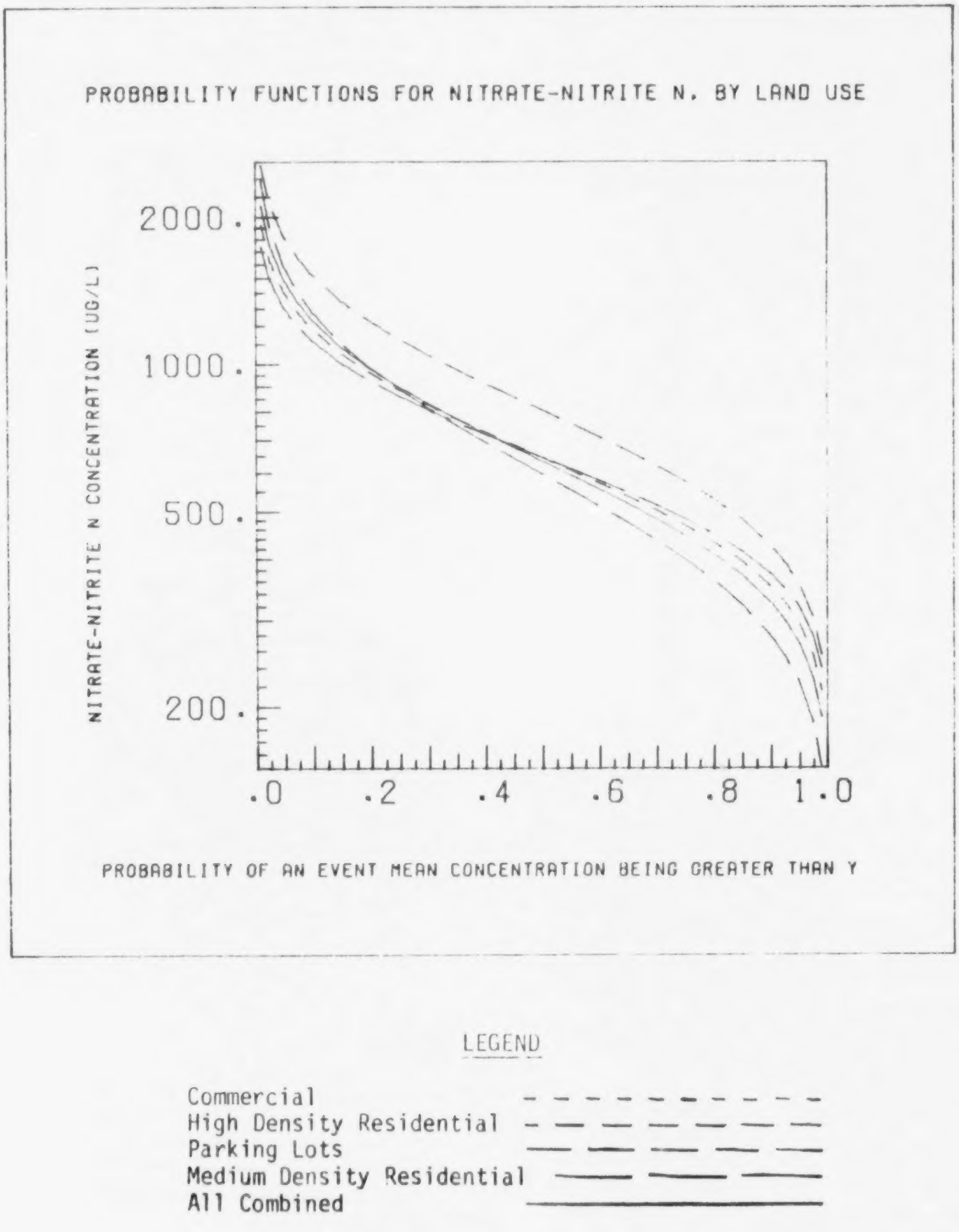
FIGURE IV.13



LEGEND

Commercial	- - - - - - - - - -
High Density Residential	- — — — — — — —
Parking Lots	—— —— —— —— ——
Medium Density Residential	——— ——— ———
All Combined	————————————

FIGURE IV.14



PROBABILITY FUNCTIONS FOR NITRATE-NITRITE N. BY LAND USE

The effect of high flow phosphorus concentrations on the trophic conditions in a receiving water is not well defined. All of the total phosphorus in the stormwater is not available for uptake by the aquatic plants. Dissolved reactive phosphorus is one fraction of the total phosphorus and all of it is considered readily available to promote growth. The dissolved reactive phosphorus averages about 20 percent of the total phosphorus in the stormwater except in the medium density residential area where the average is about 50 percent.

For five day BOD, half of the events are highest at the high density residential area and half are highest at the commercial areas. The parking lots have higher concentrations than the medium density residential, which have the lowest concentrations of all land uses. The concentration of 5 Day BOD that will lower the dissolved oxygen concentrations in a receiving stream is determined by such factors as water temperature, stream depth, stream bottom type, flow velocity, sediment oxygen demand and length of time the stream is exposed to the concentrations. These conditions have been used in the modeling of 5 Day BOD limits for wastewater treatment plants on small streams in Wisconsin and the ranges of 5 Day BOD concentrations considered a threat to dissolved oxygen concentration in some streams were exceeded by about 15 percent of the events. Of course the concentrations in the stormwater would be diluted in the streams. Almost all of the events exceeded the low flow concentration of 3 mg/l considered necessary to protect good water quality in many Wisconsin streams. A better understanding of the effect of BOD material on urban streams will require modeling the changes in dissolved oxygen with special attention given to the short duration of high 5 Day BOD concentrations in urban stream. The long term effect of settled BOD material in the bottom sediment might have a greater impact than 5 day BOD on receiving water dissolved oxygen levels.

The commercial study areas had the highest concentrations of total lead and total zinc, followed by the high density residential areas. The parking lots had the next highest concentrations, followed by the medium density residential areas. The metal concentration were higher for land uses with higher amounts of traffic. The traffic is a well documented source of these and other metals. A comparison lead and zinc concentrations with EPA acute toxicity criteria is discussed in another section of this chapter.

The commercial study areas usually had the highest concentration of a pollutant. The high density residential areas usually had the next highest concentration of a pollutant. Total phosphorus was the one major exception because the higher concentrations where observed in the high density residential areas. The parking lots and medium density residential areas always had the lowest concentrations. The ranking of the concentrations suggest the commercial and high density residential land uses are the most critical of the established urban land uses monitored in this project.

The results were consistent with the findings in Chapter V of this volume where the street surface loading values and dry deposition rates of most pollutants were higher in the commercial areas. The higher pollutant levels observed at the commercial areas were probably associated with the high traffic volumes and adjacent manufacturing activities. The number of cars in the commercial areas averaged about 15,000 per day compared with about 150 to 275 per day in the medium density residential areas. The cars not only add to the pollutant levels by exhaust emissions, tire wear and brake wear, but also track in dirt and contribute to the deterioration of the street surface. Deterioration of the street surface is probably a significant source of the solids in the street dirt (Milwaukee, 1981).

Average Concentrations by Land Use

Table IV.1 presents the average of the mean event concentration for each pollutant and land use. It allows for a quick, synoptic comparison of water quality between land uses.

The Mann Whitney test indicated a statistically significant difference (alpha = .05) exists between concentrations at different land uses for all the parameters except dissolved solids and nitrate plus nitrite. The ranking of concentrations between land uses was the same as those observed on the probability plots. The higher concentrations were usually found at the commercial and high density residential areas and the lowest concentration at the parking lots and medium density residential areas.

Results of Multi-element Scan Analyses

Multi-element scans were periodically performed on event composite water samples. The multi-element scans determined the concentrations of the following metals: silver, arsenic, beryllium, calcium, cadmium, cobalt, chromium, copper, iron, magnesium, manganese, vanadium, lead and zinc. For many of these metals, event mean concentrations were very low, often below detection limits. The metals with concentrations consistently above detection levels include calcium, cadmium, copper, iron, magnesium, manganese, vanadium, lead and zinc. These metals, with the exception of lead and zinc, were selected for further analysis. Lead and zinc were omitted from the multi-element scan analysis because these metals were more throughly sampled and analyzed in the previous characterization of mean event concentrations.

The scans provide event mean concentration data for the commercial, medium density residential and parking lot study areas from June through December, 1980 and from February through July, 1981. Event mean concentrations for stations with high density residential land use were obtained from April through July 1981. As with the other concentration data, the multi-element scan data was also found to be best described by a log normal distribution. Probability functions for the multi-element scan data were also derived using log transformed mean concentration data. The number of multi-element scan samples are as follows:

Commercial	-	State Fair 13, Wood Center 16
Medium Density Residential	-	Hastings 23, Burbank 12
High Density Residential	-	Congress 8, Lincoln 6
Parking	-	Rustler 24, Post Office 21

TABLE IV.1

GEOMETRIC MEAN CONCENTRATION BY LAND USE*

Parameter	Commercial	High Density Residential	Parking Lots	Medium Density Residential
Dissolved Solids	134	92	113	126
Suspended Solids	147	131	48	52
Volatile Suspended Solids	37	46	46	15
Total Solids	333	285	190	205
Chlorides	22	12	15	12
BOD_5	14	15	10	6
COD	86	76	55	33
Dissolved Lead	9	6	5	3
Total Lead	401	274	146	88
Total Zinc	332	236	133	69
Total Phosphorus	0.28	0.45	0.10	0.22
Dissolved Reactive Phosphorus	0.05	0.12	0.02	0.10
Nitrates, Nitrites	0.64	0.81	0.60	0.64
Ammonia	0.37	0.29	0.33	0.17
Total Kjeldahl Nitrogen	1.41	1.63	1.02	1.10
Total Organic Nitrogen	1.02	1.32	0.65	0.90

*Concentrations are in mg/l except for metals in ug/l

For the various stations and land uses, Table IV.2 and IV.3 present event mean concentrations which were exceeded by 10 percent and 50 percent of the events. The 50 percent probability figure represents the median event mean concentration for a station or land use. The 10 percent probability figure shows the event mean concentrations which were exceeded by 10 percent of the events.

Examination of the median and 10 percent probability pollutant concentrations reveal that, with the exception of cadmium, the commercial land uses had the highest concentrations, followed by high density residential, parking lot and medium density residential land uses. Generally, median event mean concentrations from commercial sites are one and one-half to two times higher than from high density residential sites, approximately two to four times higher than from parking and medium density residential sites. The differences between commercial and the other land uses are generally greater for copper. Median event mean concentrations of copper at commercial sites are generally three to four times higher than at high density residential sites and parking sites, and approximately six times higher than at medium density residential sites. Median event mean cadmium concentrations at the 10 percent probability of occurrence are highest for high density residential sites. Concentrations at those sites are approximately twice as high as at commercial and parking sites and four times as high as at medium density residential sites.

The metal concentrations are compared with the EPA acute toxicity criteria in the next section of this chapter.

Comparison with EPA Criteria

The metal concentration can be compared with the EPA acute toxicity criteria proposed in the Federal Register (V.45, N.231) as an indication of the potential impact of urban runoff on aquatic organisms. It is important to note the criteria are for ambient receiving water concentrations and not undiluted stormwater. All the metal concentrations would obviously be somewhat lower in the receiving stream. The acute toxicity is defined as a concentration that should not be exceeded at any time. The chronic criteria are 24 hour average concentration limits and will not be used in this comparison because most of the events do not last 24 hours. The toxicity of the metals is affected by the hardness of the water and the acute toxicity levels for Milwaukee County were determined using a hardness of 250 mg/l. The acute toxicity criteria for lead, zinc, cadmium, and copper were 526, 687, 8 and 52 ug/l respectively. Other metals on the EPA priority pollutant list were found at very low levels in the multi-element scan analysis.

The percentage of the events with mean event concentrations exceeding the acute toxicity criteria for the four metals are in Table IV.4. The lead and zinc percentages are from the probability analyses presented earlier. The cadmium and copper values were part of the multi-element scan analysis and the percentages were calculated from a lot fewer numbers. The percentage for each land use was determined by using the event mean concentrations from both study areas in a pair.

TABLE IV.2

EVENT MEAN CONCENTRATIONS, MG/L, OF CALCIUM, IRON, MAGNESIUM, AND MANGANESE EXCEEDED BY 10% AND 50% OF EVENTS

Station and Land Use	Calcium		Iron		Magnesium		Manganese	
	10%	50%	10%	50%	10%	50%	10%	50%
State Fair	73.0	22.9	9.6	3.7	22.2	8.9	235.7	90.7
Wood Center	73.3	27.1	17.5	4.8	29.4	9.3	442.1	136.7
Commercial	69.0	25.3	13.3	4.3	25.5	9.1	339.8	114.2
High Density Residential	35.6	18.9	7.5	1.7	13.3	5.6	280.7	51.8
Burbank	20.3	10.0	3.3	0.9	7.0	2.6	91.4	36.5
Hastings	37.3	21.1	7.1	2.9	13.3	6.9	147.6	81.3
Medium Density Residential	29.1	12.9	5.2	1.4	10.6	3.6	125.6	47.8
Rustler	30.6	14.9	4.5	0.8	12.8	5.9	116.9	40.1
Post Office	24.2	11.6	3.4	1.3	9.6	4.6	105.3	47.4
Parking Lots	27.4	13.2	4.1	1.0	11.2	5.3	110.9	42.8

TABLE IV.3

EVENT MEAN CONCENTRATIONS, UG/L, OF CADMIUM, COPPER AND VANADIUM EXCEEDED BY 10% AND 50% OF EVENTS

Station and Land use	Cadmium		Copper		Vanadium	
	10%	50%	10%	50%	10%	50%
State Fair	18.9	3.6	139.5	30.8	201.6	77.3
Wood Center	8.9	3.4	137.8	46.0	250.0	82.1
Commercial	12.4	3.5	137.7	38.4	219.5	79.7
High Density Residential	22.7	4.1	42.6	10.2	106.4	43.3
Rustler	17.0	4.2	40.5	14.7	94.4	42.0
Post Office	5.9	2.2	32.9	12.2	80.3	39.6
Parking Lot	10.9	3.2	36.5	13.4	86.5	40.8

The commercial areas had the greatest number of events exceeding the acute toxicity criteria. The percentage of events at the commercial areas exceeding the criteria was 40, 20, 20 and 38 percent for lead, zinc, cadmium and copper respectively. Only cadmium at the high density residential land use had a higher percentage value than the commercial areas. The high density residential area had the next highest number of events exceeding the criteria followed by the parking lots. The medium density residential areas had virtually none of the events exceeding criteria. Based on the proposed EPA acute toxicity criteria the stormwater from commercial and high density land uses could be a hazard to the aquatic organism in the receiving stream.

It must be emphasized, however, the proposed EPA acute toxicity criteria are only useful as a first indication of a significant hazard from urban runoff. Besides the problem of stormwater dilutions in the receiving stream, the shortcomings of using the toxic criteria lies in the differences between the laboratory conditions used to determine the lethal concentration and the conditions in the natural environment. The acute toxicity criteria was obtained from concentrations that will kill 50 percent (LC 50) of the exposed population of organism in a specified period of time. The exposure times used in the laboratory were either 48 or 96 hours and the median duration of an event in Milwaukee County is 4 hours. The LC 50 concentrations was determined by testing different concentrations of the dissolved metallic salt whereas the majority of most metals are not found in the form of free iron in the natural environment. Only 3 percent of the lead was dissolved in the stormwater and most of the lead is associated with the suspended solids. The use of the acute toxicity criteria to assess the urban runoff hazard will probably estimate a threat to the aquatic organism that is greater than exists.

The EPA toxicity criteria would be a more useful management tool if the testing was performed under conditions found in the natural environment. The acute toxicity test should relate more closely to the tolerance levels of the aquatic organisms needing protection and the chronic toxicity criteria should consider the long term risk due to settled toxics in the bottom sediments.

TABLE IV.4

PERCENTAGE OF EVENTS WITH EVENT MEAN CONCENTRATION OF TOTAL CADMIUM, COPPER, LEAD AND ZINC EXCEEDING EPA PROPOSED ACUTE TOXICITY CRITERIA FOR DISSOLVED METALS

Land Use	Cadmium	Copper	Lead	Zinc
Commercial	20	38	40	20
High Density Residential	31	7	28	18
Medium Density Residential	2	0	1	1
Parking Lots	17	4	10	5

Particle Size Analysis

Two five gallon composite samples were collected for particle size analysis at both the Hastings (medium density residential) and Rustler (parking lot) sites. The one liter bottles in the Manning water quality samplers were replaced with one large container. The suspended solids in the sample were fractionated into different particle sizes using a wet sieving process. The smallest sieve was 0.025 mm and the particles less than this size were not kept for analysis. The details of the procedure are presented in Chapter III of Volume 3. The particles in each fraction were weighed and analyzed for total phosphorus, volatile solids and total lead.

Table IV.5 list the average of two concentrations in each particle size and the average dry weight of each fraction. The range of total phosphorus and volatile solids concentrations was similar between the two study areas. Usually one particle size for each pollutant had a much higher or lower concentration. Between .025 and .250 mm, about half of the particles by weight were in the 0.125 to 0.250 mm size fraction at the Hasting Station. The Rustler station did not have a large amount of variability in weight between size fractions.

The largest particles found in the stormwater were in the 0.125 to 0.250 mm size fraction. Particles larger than 0.250 mm were either present and not captured by the sampler or were not transported in the runoff. Assuming the particle size fraction below 0.025 mm does not contain a large portion of the suspended solids, more than 20 percent of the particulate pollutants in the stormwater were present in the 0.025 to 0.063 mm sizes.

These smaller particles captured in the automatic water samples are also the ones more easily transported in the receiving stream. Between 1975 and 1977 the U.S. Geological Survey (USGS) collected high flow samples for particle size analysis in some of the stream adjacent to the study areas (Water Resources Data, 1975-1977). Most of the particles were less than 0.063 mm and more than 50 percent of the particles were usually less than 0.004 mm. Approximately 30 percent of the particles were in the range of 0.004 to 0.062 mm. A larger percentage of the particles in the receiving stream appear to be in smaller size fractions. Nonpoint source management techniques such as detention basins will be more effective if they are designed to control particle sizes less than 0.125 mm.

Long-Term BOD Concentrations

Long term BOD testing beyond the traditional five days can be helpful in evaluating the influences of oxygen demanding loads on receiving waters. Both 30 day and ultimate BOD concentrations were determined in composite event samples and the method of analysis is described in chapter 3, Volume III. A total of 29 long term BOD samples were obtained from the study areas and the number of samples per pair of sites ranged from 3 to 13. Table IV.6 has the ranges and medium of the mean event concentrations for 5 day BOD, 30 day BOD and ultimate BOD. The 5 day BOD concentrations were determined by a separate analysis in the same composite samples.

TABLE IV.5

CONCENTRATION, MG/KG, OF TOTAL P, VOLATILE SOLIDS AND TOTAL LEAD IN SUSPENDED SOLIDS BY PARTICLE SIZE*

Particle Size, mm**	Total P	Volatile Solids	Total Lead	Dry Weight, gm
		Hastings (medium density residential)		
0.025-0.038	1,400	id	id	0.04
0.038-0.063	1,950	212,000	850	0.16
0.063-0.125	1,500	179,000	930	0.18
0.125-0.250	475	398,000	335	0.50
		Rustler (parking lot)		
0.025-0.038	1,050	307,000	id	0.07
0.038-0.063	990	361,000	id	0.11
0.063-0.125	1,050	519,000	id	0.07
0.125-0.250	1,900	392,000	1,700	0.11

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* Average of two samples used for most concentrations and all dry weights average of two samples.

** All suspend solids in the samples were less than 0.250 mm and concentrations were not determined for particles less than 0.025 mm.

id insufficient data

The long term BOD concentrations were highest at the high density residential and parking lot study areas. The ratios of 5 day BOD and 30 day BOD to the ultimate BOD averaged about 3 and 1.5 respectively. The magnitude of the long term BOD concentrations were in the same range as concentrations observed in grab samples from different sites along the Wisconsin and Fox Rivers in Wisconsin.

Most of the BOD is probably associated with the suspended solids. Although the residence time of the solids in the water is highly variable, most of the BOD material will probably reach the bottom sediments before all the demand is depleted. Consequently it becomes part of the sediment oxygen demand (SOD) and might increase the rate of oxygen depleting for a period of time. The effect of the bottom sediments on the dissolved oxygen levels could be dramatically increased if the sediments were resuspended.

The State of Wisconsin uses long term BOD concentration in two models that estimate changes in dissolved oxygen concentrations, one model is for small streams and the other is used for large rivers. The models are used to set BOD limits in waste load allocation programs for point source pollution. Models could be used to determine the effect of BOD material on dissolved oxygen concentrations in urban streams. If sediment oxygen demand is important, a relationship between long term BOD and SOD should be determined before a model is used.

TABLE IV.6

MEDIANS, MAXIMUM AND MINIMUM OF THE MEAN EVENT CONCENTRATIONS, MG/L, FOR 5 DAY BOD, 30 DAY BOD AND ULTIMATE BOD*

Land Use	5 Day BOD			30 Day BOD			Ultimate BOD		
	Median	Max.	Min.	Median	Max.	Min.	Median	Max.	Min.
Commercial	11	17	6	12	24	9	14	32	12
High Density Res.	7	10	4	17	21	12	25	26	23
Parking Lots	6	39	4	16	67	11	20	92	12
Medium Density Res.	5	8	1	12	19	8	16	27	12
All	6	39	1	14	67	8	19	92	11

*Long term BOD values include carbonaceous and nitrogenous.

Fecal Bacteria Samples

Discrete grab samples have been collected randomly during events at each study area and analyzed for fecal coliform and fecal streptococci. A summary of the results of these analyses is presented in Table IV.7. The probability analysis for fecal streptococci were done for each land use, but the probability functions for fecal coliform were calculated by combining the data from all the sites. The fecal coliform data was pooled because there was not a statistically significant difference in the counts between the study areas. Figure IV.15 presents the probability functions plotted for fecal coliform and fecal streptococci. The probability plots and the log mean values indicate the fecal streptococci counts were highest at the medium density residential areas.

The full body contact recreational use (bathing water) standard for fecal coliform is as follows: based on a minimum of five samples taken over a 30 day period, the fecal coliform bacteria level should not exceed a log mean of 200 per 100 ml, nor should 10 percent of the total samples taken during any 30 day period exceed 400 per 100 ml. While the samples were not collected according to the frequencies specified in the standard, many of the fecal coliform counts found in this study exceed safe bathing water criteria. Fecal coliform counts in 79 percent of the samples exceeded 400 per 100 ml, and counts in 10 percent of the samples exceed 47,000 per 100 ml. The range in the fecal bacteria counts was very large and the log means exceeded 400 counts/100 ml at all the study areas except one.

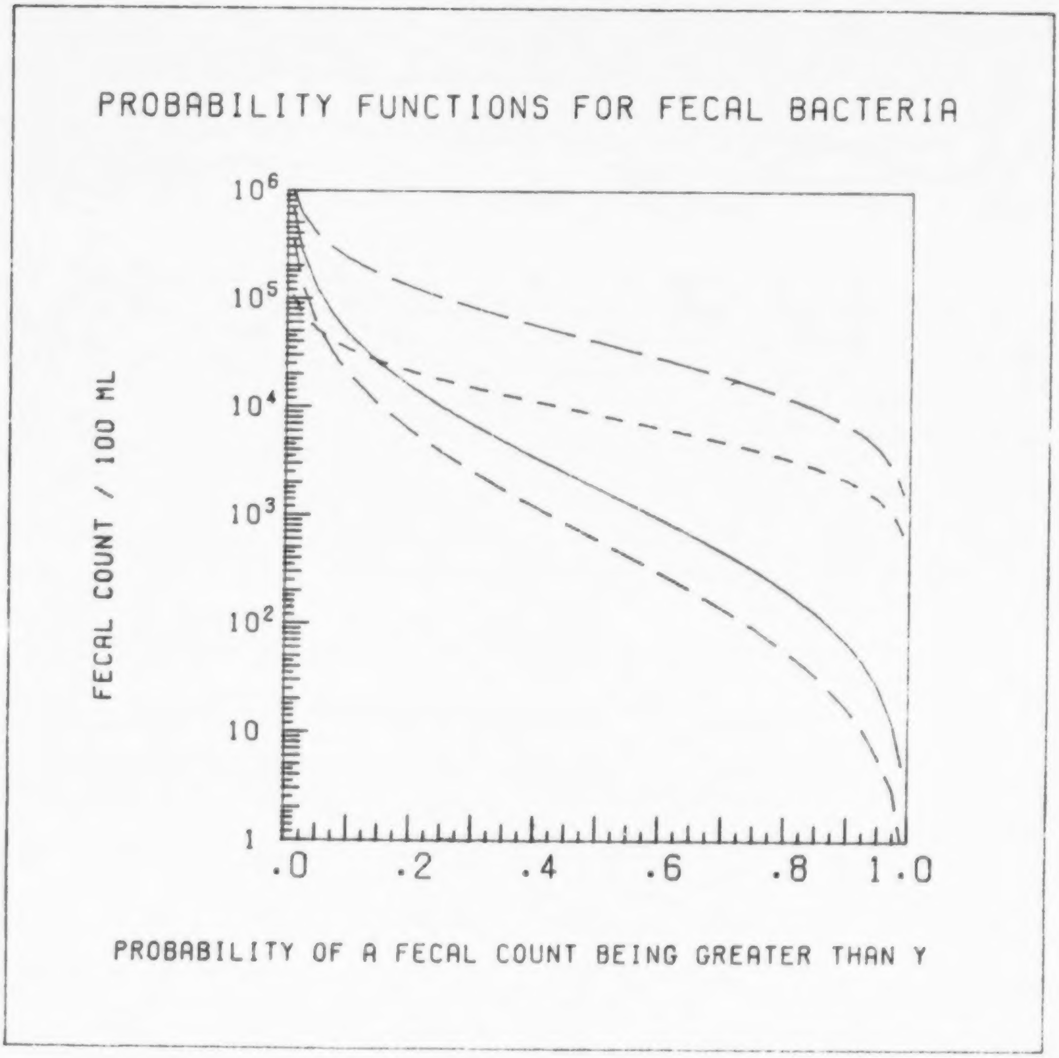
TABLE IV.7

SUMMARY OF FECAL BACTERIA SAMPLES*

		Fecal Coliform			Fecal Streptococci		
Station	N	Minimum	Log Mean	Maximum	Minimum	Log Mean	Maximum
State Fair	9	510	3,789	56,000	4,400	13,494	48,000
Wood Center	5	250	1,022	16,000	1,300	3,102	9,800
Lincoln	4	540	837	1,300	2,200	5,064	20,000
Rustler	6	5	576	13,000	10	493	9,100
Post Office	4	5	207	4,600	40	765	13,000
Burbank	5	800	17,500	410,000	7,100	43,914	430,000
Hastings	6	200	4,675	50,000	10,000	40,538	110,000

* Fecal Coliform corresponds to MFFCC/100 ml and Fecal Streptococci are in counts/100 ml.

FIGURE IV.15



Fecal Streptococci:

Commercial - - - - -
Parking — — — — —
Medium Density Residential —— —— —— —— ——

Fecal Coliform:

All Combined ————————

Seasonal Differences in Event Mean Concentrations

The average seasonal concentrations between seasons were significantly different for a number of pollutants at all the land uses. Table IV.8 list the pollutants for each land use that had a statistically significant difference between average seasonal concentrations at alpha = 0.05. The average seasonal concentration was determined by taking the mean of the logs of the event mean concentrations. The seasons were defined as: Spring = March and April; Summer = May through September; Fall = October and November; and Winter = December through February.

The average seasonal concentrations were usually highest in the winter, closely followed by the spring concentrations. The concentration in the summer and fall were usually much lower than the other seasons. Total solids and chloride were the only pollutants with concentrations significantly different between seasons for all the land uses. The chloride concentrations in the spring were about five times higher than in the summer. The high chloride concentrations in the spring and winter coincide to the time of the year when large amounts of deicing salt are applied to the streets. The winter and early spring are also periods when there are longer intervals between runoff events and a large amount of some pollutants might be more available for washoff.

Water Quality Differences Between Paired Stations

For as many as six of the pollutants the event mean concentrations between paired stations was significantly different. The samples for each study area in a pair were compared using a Mann Whitney test on untransformed data and the two sample T test on the log of the data.

Of the medium density residential stations, Burbank had significantly higher concentrations for suspended solids, volatile suspended solids, total solids and chloride. The majority of the pollutants do not have significantly different concentrations at the medium density residential and parking lot areas. The commercial study areas have the most pollutants with similar concentrations, with only three of the pollutants significantly different.

Of course the high density residential areas were not included in the comparison of paired stations, because the concentrations at the Congress station were affected by a backwater condition.

FLOW WEIGHTED AVERAGE CONCENTRATIONS

The flow weighted average concentrations were calculated by dividing the total water loading for the sampled events into the total pollutant loading for the sampled events. The individual event pollutant loading values were determined from the product of the event mean concentrations and the volume of runoff water. Between 40 and 80 events were sampled at each study area over the project period. The total pollutant and water loading values used to calculate the flow weighted average concentration were determined by simply adding together all the individual event pollutant and water loading values.

TABLE IV.8

GEOMETRIC MEAN SEASONAL CONCENTRATION OF POLLUTANTS BY LAND USE*

Pollutant	Spring	Summer	Fall	Winter
	Commercial			
Total Solids	509	286	211	940
Chloride	81	14	2	376
	High Density Residential			
Total Solids	423	235	275	id
Chlorides	27	8	id	id
Soluble P	0.08	0.16	0.06	id
	Parking Lots			
Total Solids	357	162	127	575
Chlorides	52	9	9	156
Suspended Solids	78	47	21	65
Volatile Susp. Solids	21	16	10	24
Nitrates & Nitrites	0.48	0.58	0.86	0.57
Total Lead	223	140	76	326
Total Zinc	192	107	174	196
	Medium Density Residential			
Total Solids	286	177	188	324
Chloride	27	7	8	75
Nitrate & Nitrite	0.88	0.57	0.54	0.81
Kjeldahl Nitrogen	1.28	0.98	0.94	1.57
Dissolved Lead	2	3	7	6
Total Zinc	100	52	316	106

* Concentrations are in mg/l except metals in ug/l
id insufficient data

The flow weighted concentrations are probably the best representation of an average concentration value for all the event water discharged in a year. Other methods of calculating average concentrations tend to bias the results toward the smaller events which do not represent the largest portions of the annual event water loading. For example, the geometric mean of all the event mean concentrations did not distinguish the events on the basis of magnitude which means the small and large events were weighted more equally. However, the events with the larger loading values contribute a greater percentage of the total annual runoff and are more heavily weighted in the calculation of the flow weighted average concentrations. The flow weighted average concentrations are used later in this chapter to calculate annual pollutant loading values.

Table IV.9 list the flow weighted average concentrations for solids, metals and chloride and Table IV.10 list the values for nutrients, COD and 5 day BOD. As in the other summaries of pollutant concentrations described in this chapter, the highest concentrations were usually found at the commercial study areas. The concentrations of suspended solids, total phosphorus, total lead and total zinc at the commercial area were 2, 1.2, 5 and 4 times higher respectively than the medium density residential areas. Again the notable exception was the higher total phosphorus and volatile suspended solids concentrations observed at the high density residential area. The parking lots and medium density residential areas usually had the lowest range of concentrations. The average of the flow weighted concentrations for each pair of study areas was usually higher than the geometric mean concentrations in Table IV. 1.

Flow Weighted Average Concentration for Urban and Agricultural Drainage Areas

Wisconsin is fortunate to have good event concentration and flow data from a number of nonpoint source monitoring projects. The purpose of this section, is to use the results of these projects to compare the flow weighted average concentration at the study areas, urban areas draining a mixture of urban land uses and agricultural drainage areas. The flow weighted average concentrations for the study areas were available from the previous section of this chapter. The annual event pollutant and water loading values reported for four urban and five agricultural drainage areas were used to determine the range of flow weighted average concentrations expected in a predominantly urban or agricultural area. A sufficient number of monitoring sites were selected to make the comparison of flow weighted average concentrations meaningful in many watersheds in Wisconsin.

All the urban drainage areas are adjacent to the study areas and are subwatersheds of the Menomonee River Watershed. The results from Volume 3 and 12 of the Menomonee River Pilot Watershed Project were used to calculate the flow weighted concentrations for four urban drainage areas and the Little Menomonee River (STORET number 463001) agricultural drainage areas (Bannerman 1979 and 1982). The Menomonee River Project monitored the main stem of the river and its tributaries between 1975 and 1979. All the sites emphasized collecting samples during high flows using automatic water quality samplers and continuous flow recording equipment. The urban drainage areas are almost completely urbanized and the major land use in each watershed is medium density residential. The urban areas ranged in size from 522 to 4,974

TABLE IV.9

FLOW WEIGHTED AVERAGE CONCENTRATION, MG/L, OF SOLIDS, METALS AND CHLORIDE*.

Study Area	Total Solids	Suspended Solids	Volatile Susp. Solids	Chloride	Total Lead	Total Zinc
Commercial						
State Fair	474	155	38	140	0.33	0.32
Wood Center	404	217	42	36	0.71	0.49
Parking Lots						
Rustler	240	65	18	46	0.15	0.18
Post Office	269	91	21	69	0.18	0.13
High Density Residential						
Lincoln Creek	277	174	46	22	0.32	0.27
Medium Density Residential						
Hastings	160	69	14	10	0.09	0.08
Burbank	304	118	20	13	0.12	0.11

* Calculated from all sampled events during project period.

TABLE IV.10

FLOW WEIGHTED AVERAGE CONCENTRATIONS, MG/L, OF NUTRIENTS, 5 DAY BOD AND COD*

Study Area	Total P	Soluble P	TKN	Ammonia	Nitrate + Nitrate	5 Day BOD	COD
			Commercial				
State Fair	0.32	0.12	1.39	0.36	0.67	14	87
Wood Center	0.28	0.04	1.30	0.36	0.59	11	81
			Parking Lots				
Rustler	0.16	0.03	1.00	0.38	0.63	11	53
Post Office	0.11	0.02	1.03	0.39	0.53	8	52
			High Density Residential				
Lincoln	0.40	0.10	1.74	0.32	0.82	11	68
			Medium Density Residential				
Hastings	0.23	0.11	1.06	0.23	0.67	6	34
Burbank	0.27	0.10	1.43	0.27	0.75	7	38

* Calculated from all sampled events during project period

hectares. The average of four years (1976-1979) of annual event pollutant and water loading values were used to calculate the flow weighted average concentrations for the urban areas and the Little Menomonee River drainage area. It is important to note the loading values do not include the winter season which was defined as the time between December 21 and the spring thaw.

The agricultural drainage basins are located in the lower half of Wisconsin. The Madden Branch, Apple River and Steiner Branch drainage areas are all in the southwest corner of Wisconsin, while Bruce Valley Creek is located in the west central part of the state. Cash grain crops and dairy farming are the predominant agriculture activities in the watersheds. The Madden Branch and Apple River were monitored in 1981 and 1982 as part of the Galena River Watershed Nonpoint Source Monitoring Program (Field, in press), Steiner Branch was monitored in 1978 and 1979 as part of the water quality assessment of Steiner Branch Basin Project (Field, 1982) and Bruce Valley Creek was monitored in 1980 (Water Resources, 1980). The goals at all the agricultural monitoring sites included collecting water quality samples from all the events in the monitoring period using automatic water quality samplers and continuous flow recording equipment. Whenever more than two years of monitoring results were available, the flow weighted average concentration was calculated from the average of the annual event water and pollutant loading values. As in the urban areas, the annual loading value did not include the winter period which started December 1 and ended with the spring thaw. The agricultural areas ranged in size from 1,528 to 3,900 hectares, which is similar to the urban areas. Both the urban and agricultural watersheds were relatively small since it was necessary to select monitoring station that drained only one category of land uses. There were no known point sources in any of the agricultural or urban areas.

The flow weighted average concentrations of suspended solids, total phosphorus, and total lead for the study areas, four urban areas adjacent to the study areas and the five agricultural areas are presented in Table IV.11. The concentrations for the study areas were averaged from the levels for each pair in Tables IV.9 and 10. The loading values for the three pollutants were the only ones available for the agricultural areas. The flow weighted average concentrations of suspended solids and total phosphorus were usually highest in the agricultural watersheds. The average of the suspended solids and total P flow weighted concentrations for the agricultural drainage areas were 6 and 4 times higher respectively than the average of the concentrations for the study areas. Runoff from cultivated fields and barnyards would be expected to have higher concentrations of suspended solids and total phosphorus than runoff from urban streets and lawns. As expected, the one number for lead indicated the lead concentrations were lowest in the agricultural drainage areas. Other comparisons of agricultural and urban runoff have also found the levels of lead higher in the urban stormwater (IJC, 1978). Automobile emissions are the major source of most toxic metals in the urban areas and the traffic density was obviously much lower in the agricultural areas.

All the urban drainage areas adjacent to the study areas had suspended solids concentrations higher than the study areas. The average of the suspended solids concentrations for the urban areas was 3 times higher than the study areas. The higher concentration in the urban streams suggest the established

TABLE IV.11

FLOW WEIGHTED AVERAGE EVENT CONCENTRATION, MG/L, OF THREE POLLUTANTS IN STORMWATER FROM THE STUDY AREAS, URBAN DRAINAGE AREAS ADJACENT TO STUDY AREAS AND SELECTED WISCONSIN AGRICULTURAL DRAINAGE AREAS.

Land Use and Drainage Area	Suspended Solids	Total P	Total Lead
Study Areas			
Commercial	186	0.30	0.52
Parking Lots	78	0.13	0.16
High Density Res.	174	0.46	0.32
Medium Density Res.	94	0.25	0.11
Urban Drainage Areas			
Noyes Creek	342	0.33	0.14
Honey Creek	404	0.49	0.38
Schoonmaker Creek	392	0.64	0.86
Underwood Creek	311	0.41	0.33
Agricultural Drainage Areas			
Madden Branch	1,369	2.02	id
Steiner Branch	638	0.63	id
Bruce Valley Creek	499	id	id
Apple River	631	1.03	id
L. Menomonee River	241	0.57	0.06

id insufficient data

3853T

urban land uses were not the only important source of suspended solids in the urban areas. While the study areas were selected to not have any construction activities, about three percent of the area in the urban drainage areas was found to be in some stage of development. Soil erosion at construction sites might account for the higher suspended solids concentrations found in the urban streams.

Total phosphorus concentrations were generally higher in the urban drainage areas than in the study areas. The average concentration was about two times higher. The higher total phosphorus was probably associated with the sediment eroded from construction sites. The range of lead concentration was similar for the urban areas and study areas.

ANNUAL LOADING VALUES

The average annual event pollutant loading values were determined from the products of the average annual water loading values and the flow weighted average concentration for each pollutant. The water loading values were averaged for the three years of monitoring (1980-1982). The water loading values were not measured for all the events and a linear regression relationship between rainfall and runoff was used to estimate the missing water loading values. The linear regression equations are described in Chapter III of this volume. There was an excellent relationship between runoff volume and rainfall since the coefficients of determination (r^2) ranged between 0.95 and 0.98. The calculation of the flow weighted average concentration was discussed in the preceding section of this chapter. The average annual pollutant loading values were normalized by the area of each study area.

The average annual event unit area water and pollutant loading values are listed in Tables IV.12 and 13. The water loading values were highest at the commercial and parking lot areas and lowest at the high density and medium density residential areas. The highest water loading values were about twice the magnitude of the lowest water loading values. The amounts of connected imperviousness was reflected in the trend in the water loading values. The commercial, parking lots, high density residential and medium density residential areas had about 98, 72, 43 and 36 percent connected impervious areas respectively. The results confirmed the amount of runoff generated per unit area increases with increasing amounts of connected imperviousness.

The highest event pollutant unit area loading values were observed at the commercial areas and the lowest at the medium density residential areas. The suspended solids, total phosphorus and total lead loading values at the commercial areas were about 5, 3 and 13 times higher respectively than found at the medium density residential areas. The parking lots usually followed the commercial areas in the ranking of loading values. The results were not surprising since the commercial areas had both the highest flow weighted concentrations and water loading values, and the medium density residential areas had the lowest concentration and water loadings values. However, the ranking of the parking lot was higher among the pollutant loading values than among the flow weighted concentrations. The relatively high water unit area loading values found at the parking lots elevated them to a position of higher importance among the pollutant loading values.

TABLE IV.12

AVERAGE ANNUAL EVENT UNIT AREA LOADING VALUES FOR WATER, M^3/HA, AND FOR SOLIDS, METALS AND CHLORIDE, KG/HA.*

Study Area	Water	Total Solids	Suspended Solids	Volatile Susp. Solids	Total Lead	Total Zinc	Chloride
Commercial							
State Fair	5,090	2,412	789	193	1.68	1.63	713
Wood Center	6,070	2,458	1,317	255	4.31	2.97	218
Parking Lots							
Rustler	5,620	1,348	365	101	0.84	1.01	258
Post Office	5,673	1,575	516	119	1.02	0.74	391
High Density Residential							
Lincoln Cr.	2,718	753	473	125	0.87	0.73	60
Medium Density Residential							
Hastings	2,269	363	157	34	0.20	0.18	23
Burbank	2,244	681	264	45	0.27	0.25	29

* Loading values do not include winter (December, January & February)

TABLE IV.13

AVERAGE ANNUAL EVENT UNIT AREA LOADING VALUES FOR WATER, M^3/HA, AND FOR NUTRIENTS, 5 DAY BOD AND COD, KG/HA.*

Study Area	Water	Total P	Soluble P	TKN	Ammonia	Nitrate + Nitrate	5 Day BOD	COD
				Commercial				
State Fair	5,090	1.63	0.61	7.1	1.88	3.40	72	443
Wood Center	6,070	1.70	0.24	7.9	2.24	3.58	68	492
				Parking Lots				
Rustler	5,620	0.90	0.17	5.6	2.13	3.54	61	298
Post Office	5,673	0.62	0.11	5.8	2.21	3.00	45	294
				High Density Residential				
Lincoln Cr.	2,718	1.09	0.27	4.7	0.87	2.23	30	185
				Medium Density Residential				
Hastings	2,269	0.52	0.22	2.4	0.52	1.52	14	77
Burbank	2,244	0.60	0.27	3.2	0.60	1.68	16	85

* Loading values do not include winter (December, January and February)

The water loading values were an important factor for all the pollutant loading values. The flow weighted concentrations probably indicated the magnitude of material available for washoff at each study area, but the amount of the pollutants reaching the receiving stream was probably controlled by the amount of connected impervious area. The Menomonee River Pilot Watershed Study found the pollutant loading values in urban areas to be strongly correlated with the amount of connected imperviousness. The problem of connected imperviousness is usually intensified by the occurrence of high amounts of accumulated pollutants and connected imperviousness in the same area. For example, the commercial areas not only had the highest amount of connected imperviousness, but also the results in Chapter V of Volume I suggest the commercial areas have the highest street surface loadings of most pollutants. The commercial areas were judged the most critical, using both the pollutant event unit area loading values and the flow weighted concentrations.

The following sections discuss 1) using unit area loading values to quantify the distribution of annual pollutant loading values among established urban land uses, 2) a comparison of event unit area loading values at the study areas, urban drainage areas adjacent to the study areas and selected Wisconsin agriculture drainage areas, and 3) a comparison of annual stormwater loading values and annual loading values of treated sanitary wastes.

Normalized Unit Area Loading Values for Major Urban Land Uses

The unit area loading values were used in the previous section of this chapter to identify the most critical land uses among the study areas. The ranking of the established urban land uses represented by the study areas is probably the same in most urban areas. For example, the commercial areas will usually have the highest unit area loading values of lead because they also have a high volume of traffic. However, the study areas do not represent all the major types of urban land uses.

The missing land uses include industrial, freeways, low density residential and parkland. The unit area loading values for the freeways, low density residential and parkland were obtained from the Menomonee River Pilot Watershed Study (Bannerman et al, 1979). Part of the Menomonee River Watershed is in Milwaukee County and the study areas are located inside or next to the watershed. The Menomonee Study conducted an intensive stormwater monitoring program in 1977 at ten predominantly single land use sites. Most of the sites either had a predominant land use already represented by the more homogeneous study areas or the accuracy of the data was questionable.

A heavy industrial site (STORET No. 413616) was monitored but the stormwater concentrations of some pollutants, especially metals, was probably elevated by the discharge of treated industrial wastewater into the storm sewer. The annual event unit area loading values of suspended solids, total phosphorus and total lead at the heavy industrial site were about 2.0, 2.5 and 2.5 times higher respectively than the commercial sites of this study. Because it is desirable to avoid using data affected by unknown amounts of point source discharges and many industrial sites have land use characteristics that are similar (e.g., parking lots, truck traffic, flat roofs, etc.) to the commercial sites, the industrial land use category was given the same unit area loading values as the commercial sites. Unfortunately this application of the commercial site loading values cannot be verified by previous studies, but the values would tend to underestimate the contribution from some industrial land uses, especially heavy industrial sites. The unit area loading values for freeway, low density residential areas and parklands was supported by good quality monitoring data.

The predominant land use for two of the selected sites (STORET No. 413625 and 683090) was low density residential and the third site (STORET No. 413615) had freeways as the predominant land use. The unit area loading values representing low density residential areas was an average of the loading values for the two sites. The low density residential site with a percent connected imperviousness of zero and the lowest loading values provided the loading value for parklands.

The unit area loading values for all the land uses were normalized for rainfall using historical average rainfall values summarized from the long term rain gauging stations nearest the sites. The unit area loading values can vary with changes in the amounts of rainfall and the normalized loading values should represent a more "average" year for each land use. The loading values were multiplied by the ratio of the historical average rainfall to the rainfall during the monitoring period. The rainfall averages did not include the winter period.

The normalized unit area loading for eight established urban land uses are presented in Table IV.14. The loading values for the commercial, parking lots, high density residential and medium density residential areas were the averages of the loading values for the paired sites. The highest normalized loading values of suspended solids and total lead were found for the freeways. The commercial and industrial land uses had the highest loading values of total phosphorous and the second highest loading values of suspended solids and total lead. The lowest loading values were found at the low density residential and park land uses. The total lead loading values at the freeways was about 20 and 2 times higher than the values at the medium density residential and commercial land uses respectively. The results indicate the normalized unit area loading values are higher for more density urbanized land uses. As stated for the study areas, the ranking of the normalized unit area loading values is probably the same for most urban areas in the Midwest. Extrapolation of the ranking should help an urban nonpoint source pollution control program identify the most critical land uses in a drainage area.

Extrapolation of Unit Area Loading Values

The ranking of the unit area loading values in Table IV.14 can be extrapolated to other urban areas with a reasonable amount of confidence. A ranking, however, is limited to a qualitative description of the critical land uses in an urban area. The unit area loading values would be much more useful in the role of quantifying the annual pollutant loading values for each urban land use. A nonpoint source control program would be more effective if the actual contribution from each land use was known and consequently the impact of a

TABLE IV.14

NORMALIZED ANNUAL EVENT UNIT AREA POLLUTANT LOADING VALUES, KG/HA, FOR ESTABLISHED URBAN LAND USES MONITORED IN MILWAUKEE COUNTY, WISCONSIN.*

Land Use	Suspended Solids	Total Phosphorus	Total Lead
Freeways	979	1.04	4.96
Industrial	957	1.49	2.70
Commercial	957	1.49	2.70
Parking Lots	453	0.78	0.96
High Density Residential	487	1.12	0.90
Medium Density Residential	216	0.58	0.24
Low Density Residential	11	0.04	0.01
Parks	3	0.03	0.006

*Annual loading values do not include winter and all the values are normalized for historical average rainfall values summarized from long term rain gauging stations near the monitoring sites.

management program in each land use could be determined. The land use with a high percent of the annual pollutant loading relative to its percent of the land area would receive priority in a management program. The purpose of this section is to describe the problems associated with extrapolating the loading values in Table IV.14 and present examples of calculating annual pollutant loading values using the numbers in Table IV.14.

Extrapolating unit area loading values from a monitored site to an unmonitored site has been a common practice in the past, but it is presently considered the least accurate method of estimating annual pollutant loading values. The unit area loading values are usually considered specific to the monitoring site and would not represent the loading values for a similar land use in a different location. The variability in loading values from location to location is a function of many environmental factors. A primary factor is the metereological conditions during the monitoring program and how representative they are of average conditions. The unit area loading values can only be extropolated to similar meteorological regions and the numbers in Table IV.14 have been normalized for rainfall to hopefully compensate somewhat for the variability in loading values from year to year. Other important factors effecting loading values in established urban areas include percent connected imperviousness, traffic volume and street surface conditions. The more similar these factors are between the monitored and unmonitored site, the more likely the extrapolation will produce valid results.

Experience has shown the above factors will differ significantly for many urban areas. Even adjacent monitoring sites like the study areas had some large difference in their loading values. The average annual unit area loading values of suspended solids, total phosphorous, and total lead (Tables IV. 12-13) differed between the paired sites by a factor of 1.1 to 2.6 with an average factor of 1.5. More accurate methods of estimating annual pollutant loading values would have to be able to adjust for the change in the important environmental factors between locations. Three methods that are consider more accurate are 1) to actually monitor each urban drainage area, 2) apply a verified urban runoff model such as the WURM model developed in this project and 3) generate unit area loading values for different conditions using an urban runoff model. Monitoring every urban area is obviously impractical because of the expense and time required. Modeling methods hold the most promise for estimating annual loading values for different drainage areas and at the same time provide answers to management questions in the development and evaluation of a control program, but in some situations the use of a model to estimate annual loading values might take more time and expertise than is available. If the circumstances only require a rough estimate of urban loading values and do not justify a significant expenditure of time, the decision might be made to estimate annual loading values using unit area loading values.

Before the decision is made to extrapolate unit area loading values, it is best to consider the potential error associated with the estimated annual loading values. In most cases the unit area loading values would be applied to a drainage area with a mixture of urban land uses. The annual loading values would be determined for each land use and the loading values summed to estimate the annual loading values for the entire drainage area. To evaluate the error associated with the above procedure, the annual event pollutant loading values were estimated for three urban drainage areas that are subwatersheds in the Menomonee River Watershed.

The Noyes, Honey and Schoonmaker Creeks drainage areas were monitored between 1976 and 1979 as part of the Menomonee River Pilot Watershed Project (Bannerman et al, 1979 and 1982). The size of the drainage areas ranged from 179 to 2,603 hectares and the predominant land use in each area was medium density residential. The commercial study areas are contained within the boundaries of the Honey Creek site and the medium density residential study areas are part of the Noyes Creek site. The percent connected imperviousness for each land uses in the three drainage areas was similar to the land uses in Table IV.14 and the connected imperviousness for the overall drainage areas ranged from 28 to 33 percent. The street surface conditions and traffic volumes differed between some of the land uses in the three drainage areas and Table IV.14. Each of the three drainage areas contained land uses not listed on Table IV.14. The other land uses include land under development, woodlots, unused land and row crops.

The estimates of annual event loading values of suspended solids, total phosphorous and total lead for the established urban land uses in three drainage areas are presented in Table IV.15. The loading values for each land use is the product of the area of the land use and the appropriate unit area loading values in Table IV.14. The table also list the total estimated and measured annual event loading values for each drainage area. The measured loading values are the average of four years of annual loading estimates based on comprehensive monitoring data. The ratio of the measured to estimated total annual event loading values clearly demonstrates the range of error expected with extrapolating the unit area loading values.

The trend in the ratio was different for each pollutant. All the total measured suspended solids loading values were higher than the estimates with ratios as high as 2.5. The totals for total phosphorus were essential the same for all the sites. The ratios of the total lead loading values were highly variable, ranging from 0.3 to 2.0. The presence of construction sites in all the subwatersheds especially Noyes and Honey Creek was probably responsible for the large differences between the measured and estimated suspended solids loading values. The levels of total lead are very sensitive to traffic volume and the difference in traffic volume between locations probably account for the large variability in the ratios of total lead. The similarity in the totals for total phosphorus suggest the unit area loading values will usually provide a reasonable estimate of total phosphorus loadings in other locations. The large differences found between the estimated and measured total annual loading values of suspended solids and total lead indicated the unit area loading values for these pollutants should not be extrapolated unless the impact of the potential error is balanced with the level of accuracy needed for the nonpoint source pollution control program. It should be remembered the error would probably be diminished if the unit area loading values are applied to urban drainage areas without construction sites and with volumes of traffic similar to the monitored sites.

TABLE IV.15
ESTIMATED ANNUAL EVENT POLLUTANT LOADING VALUES FOR ESTABLISHED URBAN LAND USES BASED ON UNIT AREA LOADING VALUES*

Land Use**	Honey Creek Susp. Solids	Honey Creek Total P	Honey Creek Total Lead	Noyes Creek Susp. Solids	Noyes Creek Total P	Noyes Creek Total Lead	Schoonmaker Creek Susp. Solids	Schoonmaker Creek Total P	Schoonmaker Creek Total Lead
Industrial	39	61	110	33	52	94	0	0	0
Commercial	210	328	594	58	91	165	10	15	28
Freeways	61	64	307	0	0	0	0	0	0
Parking Lots	0	0	0	12	20	25	0	0	0
High Den. Res.	81	186	149	19	45	36	1	2	2
Med. Den. Res.	354	952	394	51	137	57	33	90	37
Low Des. Res.	0	0	0	L	L	L	0	0	0
Parks	2	17	3	L	1	L	L	L	L
Total Est.	747	1608	1557	173	346	377	44	107	67
Total Meas.+	1878	2300	1401	433	425	116	64	104	138
Totals' Ratio++	2.5	1.4	0.9	2.5	1.2	0.3	1.4	1.0	2.0

* Units are Kg except suspended solids, Kg x 10^3.

** Land uses contained in the drainage areas but not included in estimates are Land Under Development, Woodlots, Raw Crops and unused lands.

+ Average of four years of monitoring.

++ Ratio is Total Measured/Total Estimated.

L Less than one.

Annual Pollutant Loading Values in Urban and Agricultural Drainage Areas

The Milwaukee NURP project represents one of the several sources of land drainage monitoring data reported for Wisconsin. The annual event pollutant and water loading values have been determined for both agricultural and urban drainage areas. The results from the best of these nonpoint source pollution monitoring projects was used to compare the annual event pollutant and water loading values at the study areas, urban areas with a mixture of urban land uses, and typical Wisconsin agricultural drainage areas.

The annual event loading values for the study areas were obtained from Table IV.12-13. The monitoring projects used to compare the flow weighted concentration were also chosen to represent annual event pollutant and water loading values for predominantly urban and agricultural drainage areas in Wisconsin.

The location of the four urban and five agricultural drainage areas and their monitoring program are described in the section of this chapter that compares the flow weighted average concentrations. The urban and agricultural monitoring projects reported the annual loading values for each year of the monitoring programs and the average of all the annual loading values for each site was used for the comparisons. The urban areas were monitored four years and the agricultural areas were monitored one or two years. The average annual event pollutant and water loading values were the same numbers used to calculate the flow weighted average concentration.

The average annual pollutant and water loading values were normalized for rainfall and the area of the watershed. To normalize for rainfall the annual loading values were multiplied by the ratio of the historical average annual rainfall to the average annual rainfall during the monitoring period. The rainfall records were summarized from the nearest long term rain gauging station. The rainfall summaries did not include the winter periods because the loading values did not evaluate the winter period. The average rainfall values and the areas of the drainage areas are listed in Table IV.16. Most of the average rainfalls during the monitoring periods were similar to the historical averages and the ratios did not significantly change the annual loading values. The study areas, obviously, had the smallest areas and the agricultural areas were all about the same size.

The normalized annual event unit area water and pollutant loading values were also listed in Table IV.16. The study areas had the highest range of water loading values followed by the urban areas. The average of the water loading values at the study areas and urban drainage areas were about four and two times higher respectively than the agricultural areas. The much higher unit area loading value was expected at the urban monitoring sites because the amount of connected imperviousness is much lower at predominantly agricultural drainage areas. The amount connected imperviousness was highest at the study areas and the study areas had a higher average water loading value than the urban drainage areas.

TABLE IV.16

NORMALIZED ANNUAL EVENT UNIT AREA POLLUTANT, KG/HA, and WATER, M^3/HA, LOADING VALUES FOR THE STUDY AREAS, URBAN DRAINAGE AREAS ADJACENT TO THE STUDY AREAS AND SELECTED WISCONSIN AGRICULTURAL DRAINAGE AREAS*

Monitoring Site	Area ha	Avg. Annual Rainfall, cm Monitored	Avg. Annual Rainfall, cm Historical	Water	Suspended Solids	Total P	Total Lead
			Study Areas				
State Fair	11.7	80	73	4,630	718	1.48	1.53
Wood Center	18.2	80	73	5,520	1,197	1.50	3.90
Lincoln Cr.	14.6	70	72	2,800	487	1.12	0.90
Burbank	25.3	70	72	2,310	272	0.62	0.28
Hastings	13.3	70	72	2,340	161	0.54	0.21
			Urban Drainage Area				
Noyes Creek	522	72	68	2,240	767	0.75	0.21
Honey Creek	2,803	72	68	1,625	656	0.80	0.51
Schoonmaker Cr.	179	72	68	896	351	0.57	0.77
Underwood Cr.	4,974	72	68	697	217	0.30	0.12
			Agricultural Drainage Area				
Madden Branch	3,900	88	80	550	752	1.11	id
Steiner Branch	1,528	82	80	1,164	743	0.74	id
Bruce Valley	2,615	109	73	940	470	id	id
Apple River	2,419	95	80	612	386	0.63	id
L. Menomonee R.	2,144	72	68	769	185	0.44	0.01

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* Annual event loading values do not include winter and are normalized for historical average rainfall values summarized from long term rain gauging station near the monitoring sites.

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In contrast to the water loading values, the range of suspended solids and total phosphorus loading values were similar for all the categories of monitoring sites. However, the one total lead loading values in the agricultural areas indicates the urban lead loading values were much higher than the agricultural areas. The average of the suspended solids loading values was about the same for all categories. The average of total phosphorus loading values for the study areas was slightly higher than the other categories of monitoring sites. The commercial areas were responsible for the slightly higher average of the total phosphorus loading values.

Although it was surprising to find a similar range of suspended solids and total phosphorus unit area loading values at the agricultural and urban monitoring sites, an explanation was provided by the differences in the water loading values and flow weighted concentrations. The agricultural areas had much higher flow weighted average concentrations of suspended solids and total P than the urban monitoring sites, but most of the unit area water loading values were much higher at the urban monitoring sites. The high unit area water loading values compensated for the lower concentrations at the urban monitoring sites and the lower unit area water loading values at the agricultural areas reduced the impact of the high concentrations. The greater availability of solids and total phosphorus in an agricultural areas was balanced by the larger yield of water in an urban area. The similarity in the urban and agricultural unit areas loading values must be considered in the development of a watershed management plan.

Comparison of Stormwater and Treated Sanitary Wastewater

Point sources of pollution must be included in the evaluation of the total pollution problem in an urban area. Sanitary wastewater is the only point source of pollution in the study areas. All the sanitary wastewater conveyed from the study areas is treated before it is discharged to Lake Michigan. The annual pollutant loading in the treated sanitary wastewater from the study areas was estimated using an average annual contribution per capita.

The annual average per capita loading of suspended solids, total phosphorus and 5 day BOD was calculated at the South Milwaukee and Port Washington sewage treatment plants using 1982 discharge monitoring report forms (SEMORE form). The sanitary wastewater from the study areas is not treated at these plants, but the plants receive most of their waste from similar residential areas. The Port Washington plant serves a population of 8,752 and South Milwaukee plant handles 23,297 people. Both plants used secondary methods of treatment and they were in compliance with their permits.

The per capita annual loading values were determined by dividing the population into the annual effluent loading values. The per capita annual loading values of suspended solids, total phosphorus and 5 day BOD were 2.6, 0.1 and 3.9 kg/yr respectively at the South Milwaukee plant and 2.2, 0.2, and 3.0 kg/yr respectively at the Port Washington plant. The averages of the annual per capita effluent pollutant loading values were 2.4, 0.15 and 3.4 kg/yr respectively at the two treatment plants.

The average of the per capita loading values at the two plants was multiplied times the population of each residential study area to determine the annual treated sanitary wastewater loading values. The populations for Lincoln Creek, Hastings and Burbank residential areas were 675, 565 and 960 respectively. The annual suspended solids, total phosphorus and 5 day BOd loading values are listed in Table IV.17. The urban stormwater contributed the majority of the total suspended solids, but only about ten percent of the total 5 day BOD and total phosphorus loading.

If the treated sanitary wastewater was discharged to a stream receiving urban stormwater, the treated sanitary wastewater would be a more important source of total phosphorus and 5 day BOD. Both the treatment plant effluent and the stormwater in the Milwaukee Metropolitan area enter the inshore zone of Lake Michigan and efforts to control BOD and total phosphorus should carefully weigh the relative contributions of the treatment plants before managing the total phosphorus and BOD in the urban stormwater. This point is especially important if there is a need to control the total amount of BOD and total phosphorus entering the reach of a small stream directly below a town or city.

TABLE IV.17

COMPARISON OF ANNUAL SUSPENDED SOLIDS, TOTAL PHOSPHORUS AND BOD LOADING VALUES, KG, IN STUDY AREAS' TREATED SANITARY WASTEWATER AND URBAN STORMWATER

Pollutant	Treated Sanitary Wastewater	Urban Stormwater	Total Pollutant Loading	% Urban Stormwater
Lincoln Creek (High Density Residential)				
Suspended Solids	1,620	6,906	8,526	81
Total Phosphorus	101	16	117	14
BOD	2,295	438	2,733	16
Hastings (Medium Density Residential)				
Suspended Solids	1,404	2,088	3,492	60
Total Phosphorus	88	7	95	7
BOD	1,989	186	2,175	9
Burbank (Medium Density Residential)				
Suspended Solids	2,304	6,679	8,983	74
Total Phosphorus	144	15	159	9
BOD	3,264	405	3,669	11

IMPACT ON RECEIVING WATER

Determining the impact of urban stormwater on the beneficial uses of a receiving stream was not an objective of the Milwaukee NURP project. The impact on receiving water, however, will always be an important consideration in the decision to implement an urban nonpoint source control program. An evaluation of water quality effects of urban runoff on Coyote Creek near San Jose, California found the urbanized portion of the stream more heavily polluted than the rural portion (Pitt, 1982). Previous water quality monitoring projects have evaluated the water quality conditions in the main stem of the Menomonee River, which drains a large portion of the Milwaukee Metropolitan area and contains half of the study areas. Urban and agricultural runoff greatly increases the pollutant levels in the Menomonee River, since about 90 percent of the suspended solids and 60 percent of the total phosphorus loading values at the mouth of the river occurred during event flows (Bannerman et al, 1979). This project provides an opportunity to summarize the water quality data from the earlier Menomonee River projects in an effort to gain some further insight into the impacts of urban stormwater on receiving streams.

All the water samples collected in this project measured event mean concentrations inside the stormsewers and not in the receiving stream. Because of dilution effects and the short duration of runoff events it is very difficult to determine the impact of stormwater without direct measurements of water quality in the receiving streams. Beneficial uses of a stream are usually related to the pollutant concentrations in the water and bottom sediments and to the structure of fish and macroinvertebrate communities. These parameters have been measured in the Menomonee River as part of the Menomonee River Pilot Watershed Study (Bannerman et al, 1979) and the 208 plan for the Menomonee River Watershed (SEWRPC, 1976).

The diversity of land uses in the Menomonee River Watershed provide a good opportunity to evaluate the impact of urban stormwater. The 355 square kilometers of the Menomonee River Watershed were about 49 percent urban and 51 percent rural land uses in 1975 (Walesh et al, 1979). The predominant rural land uses were row crops, pasture and small grains, while the predominant urban land uses were medium density residential and commercial. Most of the rural land is in the upper quarter of the watershed. The middle quarter of the watershed is a transition area with a mixture of mostly residential and some rural land areas. The lower half of the watershed changes from medium density residential to mostly commercial and heavy industrial land uses at the mouth of the Menomonee River.

The importance of urbanization can be evaluated by comparing the water quality in the rural and urban segments of the river. The drainage areas directly adjacent to three of the mainstem river monitoring sites (STORET numbers 673001, 683001 and 413005) were selected as the boundaries of the upper, middle and lower segments of the river respectively. The percent urbanization in each adjacent drainage area was 14, 45 and 71 respectively with corresponding drainage areas of 4774, 6653, and 11,529 hectares. Water and macroinvertebrate samples were obtained at the three sites and bottom sediment samples were obtained at and above the sites. A complete description of the sampling locations, methods and data for the water and macroinvertebrate sampling is in Volume 3 of the Menomonee River Study final report (Bannerman et al, 1979) and the same information on the bottom sediment sampling is in Volume 6 (Dong et al, 1979). All the water quality measurements were obtained in 1977 except for one of the macroinvertebrate samples collected in 1976 at station 683001.

The annual event flow weighted average concentrations of suspended solids, total phosphorus and total lead, biotic index values and bottom sediment concentration of total lead for the three segments of the Menomonee River are listed in Table IV.18. Flow weighted average concentrations were determined by dividing the annual event water loading values into the estimates of annual event pollutant loading values. The concentrations of suspended solids and total lead increased dramatically from the rural to the urban segments of the river. The suspended solids and total lead concentrations in the urban segments were about ten times higher than in the rural segment of the river. In contrast to the other pollutants the total phosphorus concentrations were about the same at all sites.

The comparison between agricultural and urban concentrations in a previous section of this chapter indicated the suspended solids and total phosphorus concentrations are usually higher at agricultural sites. An agricultural site (11 percent urban) on the Little Menomonee River, a tributary to the Menomonee River, supported these findings. Suspended solids and total phosphorus concentrations were 641 and 1.00 mg/l respectively. Those concentrations are 1.3 and 1.7 times higher respectively than the lower segment of the river. The total lead concentration, however, at the lower, more urbanized segment was 3.6 times higher than the concentration of 0.06 mg/l at the Little Menomonee River site. As expected, the larger volume of traffic produced higher concentrations of lead in the urban segment. The comparison of the total phosphorus concentrations was affected by the discharge from sewage treatment plants above all the mainstem sites. The reasons for the relatively low suspended solids concentration in the rural segment are not clear, but the results do indicate the suspended solids concentrations increase with increasing urbanization on the mainstem of the Menomonee River. In addition, the unit area loading values of suspended solids at both the upper segment and the Little Menomonee River site were at least 1.3 times lower than the lower segment, which further emphasizes the importance of the urban stormwater. The trend in the unit area loading values is also consistent with the findings in the previous section of this chapter that compares unit area loading values in agricultural and urban drainage areas.

The bottom sediment concentrations of total lead in Table IV.18 were averages of samples taken from 2, 4 and 2 locations in the upper, middle and lower segments of the river respectively. The higher concentrations of lead in the urban portions of the Menomonee River were reflected in higher bottom sediment concentrations. The bottom sediment concentrations in the urban segments were about four times higher than in the rural portion for the sand and silt, and about ten times higher for clay. The bottom sediment concentrations of lead at the Little Menomonee River site were also low with concentrations of 2, 7, 36 ug/g for sand, silt and clay sizes respectively. The average concentrations of total lead in the sand, silt and clay particle sizes of the predominant soil types in the watershed were 5, 11 and 48 ug/g respectively (Dong et al, 1979). The similarity between the total lead concentrations in the soils and bottom sediments of the rural river segment suggest the bottom sediments are not contaminated with lead, whereas the bottom sediments in the urban river segments are clearly contaminated. The bottom sediment concentrations of cadmium, zinc and copper were also higher in the two urban segments of the river than in the rural segment.

Macroinvertebrates are sensitive to water quality and, because of their relative immobility have been used as water quality indicators. Species vary in the types and concentrations of pollutants they tolerate. Hilsenhoff (1977) developed a biotic index wherein organisms are assigned index values based on their ability to tolerate varying degrees of pollution. The biotic index values range from 0 to 5. Biotic Index values of 1.75 to 2.75 indicate good water quality, values of 3.00 to 3.75 indicate significant disturbance and poor water quality, and values greater than 3.75 indicate gross disturbances and very poor water quality. Biotic index values for the one Surber sample collected at each site indicate poor to very poor water quality conditions existed in all the portions of the Menomonee River. A biotic index value of 3.8 at the Little Menomonee River site indicate poor water quality also exists in that tributary to the Menomonee River. The structure of the macroinvertebrate community in the two urban segments was probably influenced by a combination of factors such as high current velocity, toxic pollutants, and low levels of dissolved oxygen. The macroinvertebrate community in the rural segment is probably influenced by nutrient enrichment from agricultural runoff and discharges from a small sewage treatment plant. The excessive nutrients probably promote sufficient algae growth to lower the levels of dissolved oxygen.

The fish population of the Menomonee River watershed stream system was inventoried in late summer 1973 by the Department of Natural Resource, Bureau of Research (SEWRPC, 1976). Two, three and four fish shocking sites were located in the segments of the river directly above monitoring sites 673001, 683001 and 413005 (upper, middle and lower) respectively. The fish population at all the sites was characterized by a dominance of pollution tolerant and very tolerant species. Like the biotic index values, the structure of the fish community is an index of the stream water quality. The lack of the pollution intolerant species at all the sites indicated poor water quality conditions existed in all portions of the Menomonee River. Night time sags in the dissolved oxygen levels have been documented for the river and the low levels of dissolved oxygen are probably a major factor limiting the survival of more desirable fish species.

The dominance of the pollution tolerant fish in all segments of the river does not indicate the variability in the number of fish found. The average number of fish surveyed at each site was 800,165 and 20 in the upper, middle and lower reaches respectively. The sites in the upper reach had an average of 40 times more fish than those in the lower reach. Although the upper segment only had two of the nine sites, the number of fish collected at the upper sites represented 74 percent of the total number of fish surveyed. The lower segment maintains a significantly reduced and dispersed fish population, and in some sites, was virtually devoid of even very tolerant fish. The fish population in the urban areas is possibly responding to the additional effects of higher toxic concentrations and the generally poorer condition of their habitat in a segment of the river channel characterized by channelization and high flow velocities. However, it is important to note the above discussion is based on only one fish survey, and the migratory habits of fish generally require more survey work to better establish the distribution of a fish population.

Agricultural and urban runoff are degrading the water quality of the Menomonee River. The high biotic index values and dominance of pollution tolerant fish species indicate the entire mainstem of the river in characterized by poor water quality. However, water quality, as measured by pollutant concentrations, bottom sediment concentrations and fish number, decreases dramatically as the river passes through the urban areas. Since the greatest volume of pollutants enters the Menomonee River during runoff events, urban runoff is the largest source of most pollutants in the urban segments of the Menomonee River. Although insufficient data was collected to establish a cause and effect relationship between the observed degradation of water quality and urban runoff, urban runoff must be an influencing factor diminishing the water quality of the receiving waters. To restore the beneficial use of the river, urban as well as agricultural nonpoint source control programs are needed.

TABLE IV.18
ANNUAL EVENT FLOW WEIGHTED AVERAGE CONCENTRATIONS, mg/l,
BOTTOM SEDIMENT CONCENTRATIONS OF LEAD, ug/kg, AND
BIOTIC INDEX VALUES IN THE MENOMONEE RIVER*

River Segment	Percent Urban Area	Flow Weighted Concentration Suspended Solids	Total P	Total Lead	Lead in Different Bottom Sediment Particle Sizes Sand	Silt	Clay	Biotic Index Values
Upper	14	50	0.47	0.024	6	12	33	4.2
Middle	45	330	0.61	0.042	25	63	373	3.5
Lower	71	490	0.58	0.219	24	63	301	4.5

* Source of data for concentrations and biotic index values is volume 3 of Menomonee River Study final report (Bannerman et al, 1979) and source for bottom sediments is volume 6 of final report (Dong et al, 1979).

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SUMMARY AND CONCLUSIONS

1. Among the land uses characterized in this study, stormwater runoff concentrations of most pollutants were highest from the commercial areas, followed by the high density residential areas. The concentration of total phosphorus and suspended volatile solids were an exception with the highest concentrations at the high density residential areas. The lowest concentrations were usually found at the medium density residential and parking lot areas. The flow weighted average concentrations of suspended solids from commercial and the high density residential areas were about two times higher than from the medium density residential areas The concentrations of total lead at commercial and high density residential areas were about 5 and 3 times higher respectively than from medium density residential areas. The pollutant concentrations at the study areas indicated the commercial areas are the most critical established urban land use.

2. The proposed EPA acute toxicity criteria for copper, cadmium, lead and zinc were exceeded by some events at all the study areas. The commercial and high density residential areas had the greatest number of events with mean event concentrations exceeding the criteria. The percentage of the events exceeding the criteria at the commercial areas was 38, 20, 40, 20 percent for copper, cadmium, lead and zinc respectively. The proposed EPA acute toxicity criteria indicated the stormwater from commercial and high density land uses could be a hazard to aquatic organisms.

3. Fecal coliform counts in urban runoff greatly exceed safe bathing water criteria. The high fecal counts suggest that body contact be limited in urban streams and that levels of fecal coliforms in receiving waters be closely monitored following rainfall.

4. The average seasonal concentration of total solids and chlorides were highest in the winter and spring seasons for all the land uses. The chloride concentrations in the spring were about five times higher than in the summer. The seasonal chloride concentrations reflected the impact of road salting in the winter and spring.

5. The urban areas with the greatest amount of connected imperviousness generate the greatest amount of runoff. Higher pollutant loading values are associated with larger amounts of runoff. The hydrologic response of an area may be the most significant factor determining the subsequent level of stormwater pollution.

6. A ranking of pollutant loads for urban land uses monitored in this study and previous studies in the Milwaukee area indicates that the commercial, industrial and freeway land uses are the most critical. The parks and low density residential land uses generate the least amount of pollutants. Annual unit area loading values of suspended solids from commercial and high density residential areas are about five and two times higher respectively than from medium density residential areas and the annual unit area loads of total lead are thirteen and four times higher respectively.

7. Urban and agricultural land uses in Wisconsin generate similar stormwater loads of suspended solids and total phosphorus on a unit area basis. Although the agricultural land use have higher concentrations of these pollutants than urban land use, the loading values are similar because the urban land uses generate much higher volumes of runoff. Stormwater loading values of total lead and most other heavy metals are much higher from urban areas than agricultural areas.

8. The amount of total phosphorus and BOD discharged from residential areas via treated secondary wastewater is greater than the amounts contained in stormwater runoff. However, the amount of suspended solids discharged in residential stormwater is much greater than in treated secondary effluent.

9. Urban areas with construction activities have higher concentrations and annual loading values of suspended solids than established urban land uses. The concentrations and annual loading values are about three and two times higher respectively for developing urban areas.

10. The quality of the Menomonee River decreases as it flows from its agricultural headwaters through Milwaukee to Lake Michigan. This degradation is reflected by the decreasing numbers of fish and increasing levels of pollutants in the water and bottom sediments. The fish population may be responding to a number of variables, including accumulated toxins in bottom sediments and changes in the hydrology and morphology of the river. Yet, in the absence of significant known point sources of pollution, the dramatic decline in the quality of the river system as it flows through Milwaukee demonstrates that urban stormwater can seriously degrade the quality, aquatic viability, and beneficial uses of receiving waters.

CHAPTER V.

SOURCES OF URBAN STORMWATER CONTAMINANTS

INTRODUCTION

Urban stormwater contaminant sources can conceptually be divided into three categories. Primary source contaminants are the original materials or processes from which stormwater contaminants are initially derived. They include industrial and automotive emissions, wind blown dust and dirt, tire, brake and clutch wear, eroding roadway materials, exposed soils, deicing salts and sands, etc. (APWA, 1969; Pitt and Amy, 1973; Sartor and Boyd, 1974; Pitt, 1979; Novotny and Chesters, 1981). Most primary source contaminants are in turn deposited or made available to stormwater as secondary source contaminants. Secondary sources are the immediate origins of stormwater contaminants at the time of an event. They include streets, roofs, driveways, parking lots, lawns, catch basins, and rainfall itself. Tertiary source contaminants are the stormwater collector systems. They are the final point of collection and conveyance prior to discharge into receiving waters. From the standpoint of the receiving streams, the source of contaminants is the outlets of the storm sewers.

Several researchers (listed above) have evaluated primary, secondary and tertiary sources of contaminants and their controls. Primary source control involves the reduction or elimination of primary sources of contaminants, e.g., removing lead from gasoline, or reducing industrial and automotive emissions. Secondary source control involves "housekeeping" practices, e.g., street sweeping, catch basin cleaning, leaf pickup, etc.. Tertiary source control involves the treatment of stormwater prior to discharge into receiving streams. The most practical form of treatment is settling in sediment basins. In urbanizing areas, another form of tertiary control rapidly becoming more common is the practice of developing urban areas in a manner that will minimize subsequent runoff.

A major difference between primary, secondary and tertiary control lies in the distribution of costs. With most types of primary control, the individuals otherwise responsible for the generation of contaminants are made responsible for the costs of controlling them. With most types of secondary control, and tertiary control in developed areas, the costs are borne by the public at large.

The primary stormwater control mechanism examined in this project was street sweeping. Street sweeping at its best is only as effective as is the relative magnitude of street surface contaminants compared to other secondary sources of contaminants. Accordingly, street surface contaminants, atmospheric wet and dry deposition, and rooftop runoff were monitored, and the results of which are presented in this chapter.

STREET SURFACE CONTAMINANTS

Street surface contaminants were monitored in each of the designated test areas, from May, 1980 until June, 1982. The purpose of this monitoring was to characterize the sources, composition and magnitude of street surface pollutants, and to better understand the dynamic processes of pollutant deposition, resuspension, accumulation, street sweeper removal and rainfall-washoff. With the exception of street sweeper removal, these are discussed in this chapter. Street sweeper removal is discussed in Chapter VI, IMPACTS OF STREET SWEEPING ON URBAN STORMWATER QUALITY.

Street surface pollutants are organic and inorganic materials and debris on street surfaces. They include atmospherically derived particulates (automotive and industrial emissions, wind blown dust and dirt, etc.), materials deposited by passing traffic (tire, clutch and brake wear, leaked oil, and tracked in debris on tires and car underbodies), vegetative materials (primarily leaves and grass clippings), materials washed in by previous rainfalls, animal wastes, eroded roadway materials, deicing and antiskid compounds, and litter (Novotny and Chesters, 1981). Potential stormwater pollution problems associated with street runoff include aquatic habitat siltation, heavy metal toxicity, eutrophication, and dissolved oxygen depletion.

The street surface monitoring procedures used in this study were modeled after those used by Pitt (1979). They are fully described in Volume III, Chapter III of this report. Street surface samples were collected by WDNR field personnel. For each sample, several subsamples were taken across randomly selected street widths, using a vacuum sampler apparatus, in sufficient number to derive 25 percent error terms on the overall street loading estimate. This usually involved taking 25 to 30 subsamples per sample. Following collection, the samples were processed at the USGS lab in Madison, Wisconsin. The samples were weighed and subdivided into several fractions, including grass, leaves, and different particle sizes (less than .031, .063, .125, .25, .5, 1.0, 2.0, and 4.0 mm). Composited subsamples were sent to the Wisconsin State Lab of Hygiene for analysis of total lead, total phosphorus, COD and volatile solids.

Following initial subsampling at the parking lot (Rustler) it was decided to stratify the parking lot into two areas. One half was asphalt in poor condition (Rustler Rough) and the other was asphalt in good condition (Rustler Smooth). Each was sampled separately thereafter. In addition to the two Rustler sites, streets at State Fair, Congress and Hastings were also monitored. Table V.1 indicates the number of samples that were collected at each site.

Particle Size Distribution And Concentrations Of Street Surface Contaminants

Figure V.1 depicts average particle size distribution of total solids at the study sites. Most of the material is in the sand size fraction (.063-2.0 mm), with smaller amounts of finer material, gravel, grass and leaves. Only the two residential sites (Congress and Hastings) have appreciable amounts of

Table V.1

STREET SURFACE SAMPLING SUMMARY

	Total Number of Street Surface Samples Collected	Total Number of Accumulation* Periods	Total Number of Street Sweeping Evaluations	Total Number of Rainfall/Washoff Evaluations
State Fair	159	22	39	2
Congress	116	27	30	7
Rustler Rough	81	30	9	2
Rustler Smooth	86	39	11	3
Hastings	112	24	24	5
Total	554	142	113	19

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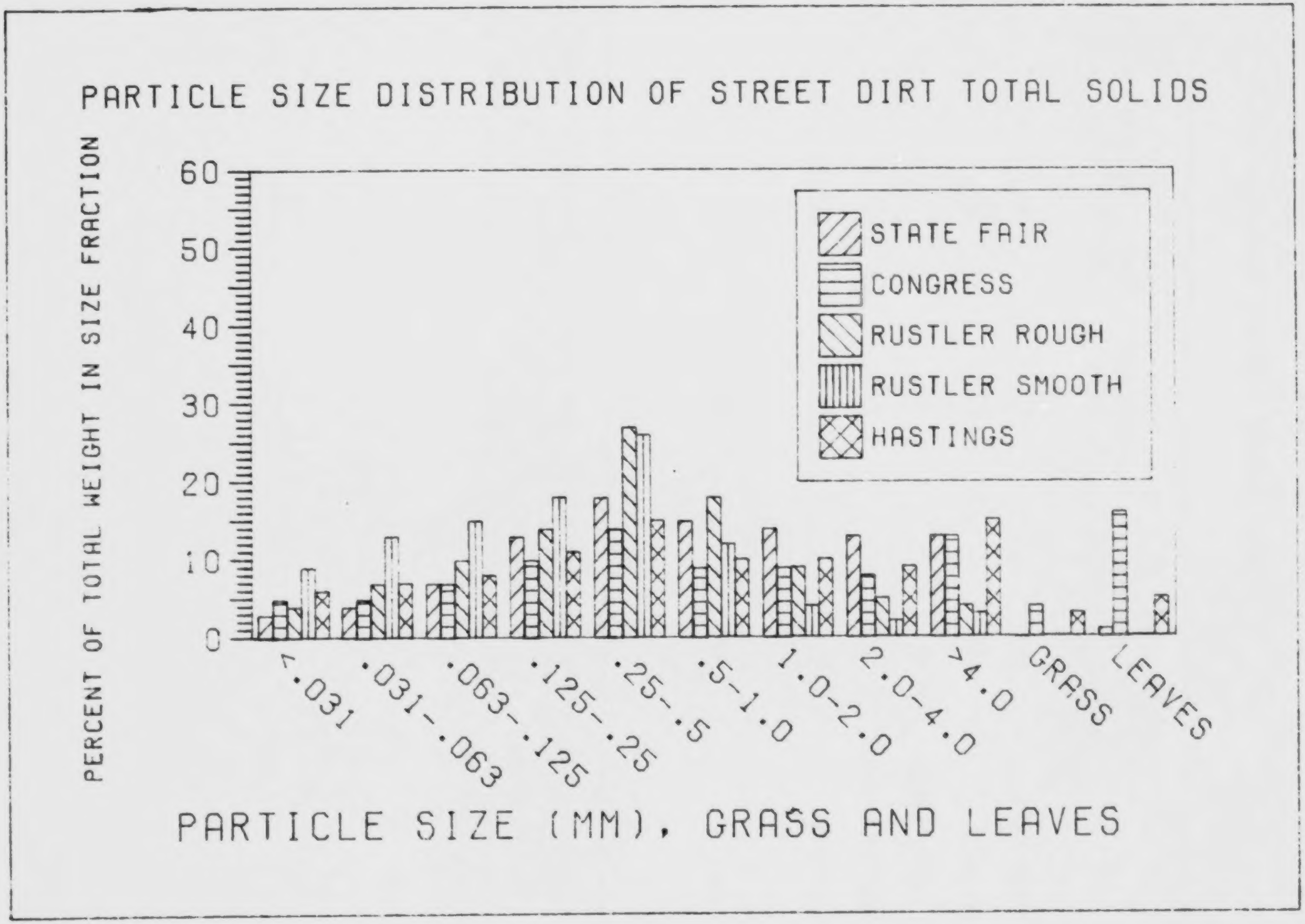
* Accumulation periods are periods of time between street surface sampling events without intervening street sweeping or rainfalls greater than .1 inch. If an area was sampled on the first, third and eighth day of a month, without intervening rainfall or sweeping, there would be three accumulation periods (1st-3rd, 3rd-8th, and 1st-8th).

FIGURE V.1


PARTICLE SIZE DISTRIBUTION OF STREET DIRT TOTAL SOLIDS
PERCENT OF TOTAL WEIGHT IN SIZE FRACTION
60
50
40
30
20
10
0
STATE FAIR
CONGRESS
RUSTLER ROUGH
RUSTLER SMOOTH
HASTINGS
<.031
.031-.063
.063-.125
.125-.25
.25-.5
.5-1.0
1.0-2.0
2.0-4.0
>4.0
GRASS
LEAVES
PARTICLE SIZE (MM), GRASS AND LEAVES

grass and leaves, especially Congress. Otherwise there is little difference in particle size distribution among the three nonparking sites. The difference between the two Rustler sites is evident. Rustler Smooth has greater percentages of particles smaller than .25 mm than does Rustler Rough, and vice-versa for particles larger than .25 mm.

Figure V.2 depicts average lead concentration at the various sites for the various particle sizes. The impact of heavy traffic at State Fair is evident. Lead concentrations here are twice as high as any other site. At all the sites, lead concentrations peak in the .031-.25 mm range. Lead concentrations in larger particles are very low.

Figure V.3 depicts average total phosphorus concentrations. They are highest in the smallest particles, and decrease slowly with increasing particle size. Concentrations in the largest particles are about half of those in the smallest particles. Phosphorus concentrations are highest at the residential sites, where the particle size fractions likely include significant amounts of disintegrated organic matter.

Volatile solids and COD concentrations follow similar patterns (Figures V.4-5). Concentrations of volatile solids and COD in the smaller than .031 mm size fraction are roughly twice as high as in the remaining size fractions. Congress again has COD and volatile solids concentrations higher than the other sites.

For each of the above parameters, analysis of variance indicates significant differences in the concentrations between particle sizes at each site, and between sites for each particle size (alpha = .05)

When individual particle size loads are coupled with their respective concentrations, individual pollutant load distributions can be obtained (Figures V.6-10) Lead predominates in the fine to medium sand size fractions because both concentrations and solids are highest in these sizes. The particle size distribution of street surface pollutants affects street sweeper removal and more strongly affects rainfall-washoff.

Variations In Street Loads Between Sites

Several factors combine to effect the loading of street surface contaminants. Variables such as land use, pavement type and condition, traffic patterns, etc., will affect the street loads at different sites. Variables such as season, wind, rainfall and street sweeping will effect the street loads at any site over time. The primary variables effecting spatial distribution of street loads include land use, traffic, street surface texture and condition, and localized deposition of atmospheric particulates. The impact of land use is well documented (Sartor and Boyd, 1974; Pitt, 1979; Shaheen, 1975). Areas with high amounts of traffic receive high amounts of traffic related pollutants. Industrial areas receive greater atmospheric fallout of industrial emissions. Areas with heavy pedestrian traffic are littered, etc.. One significant variable affecting street loads is street texture and condition (Pitt, 1983).

FIGURE V.2

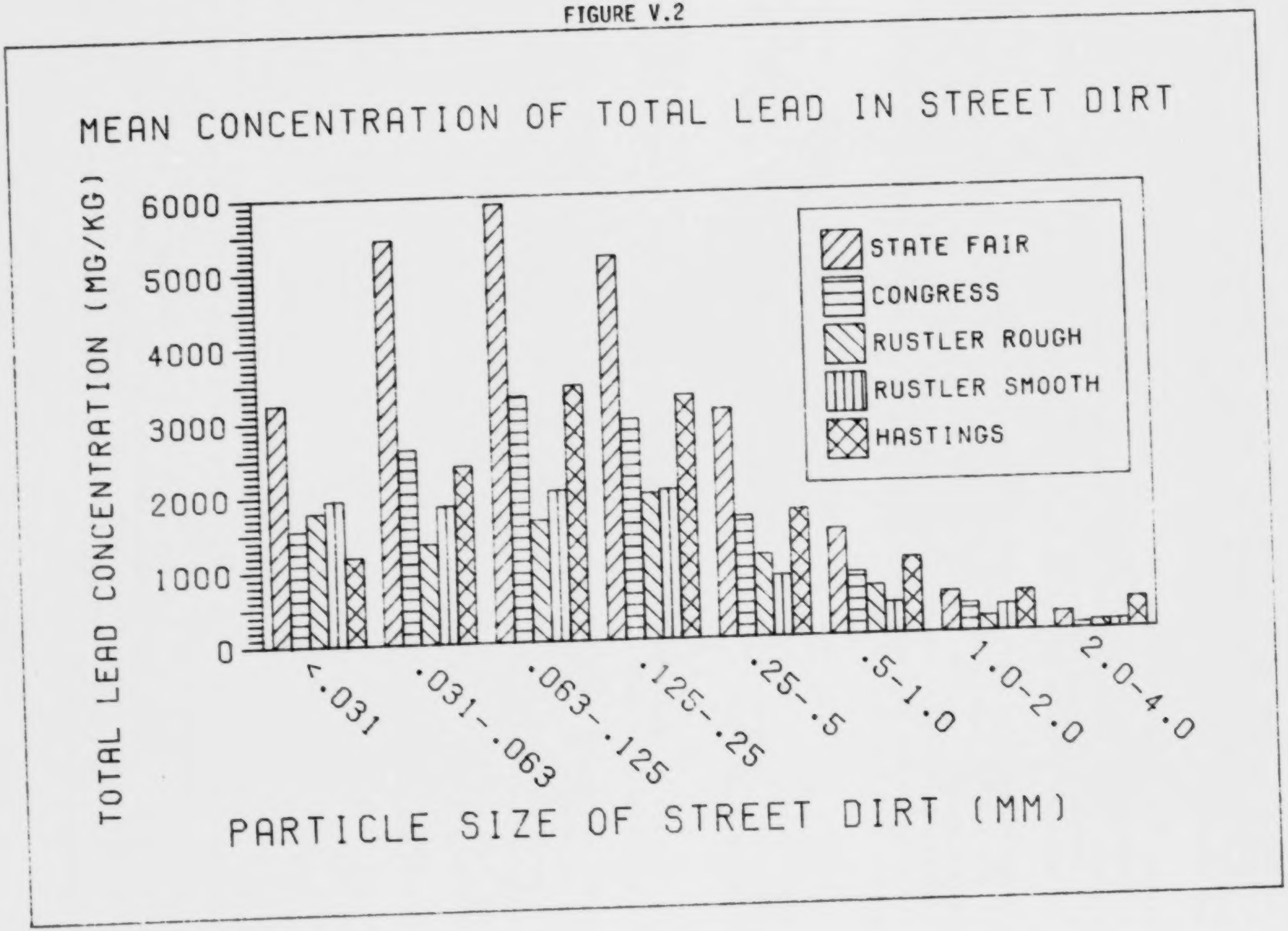
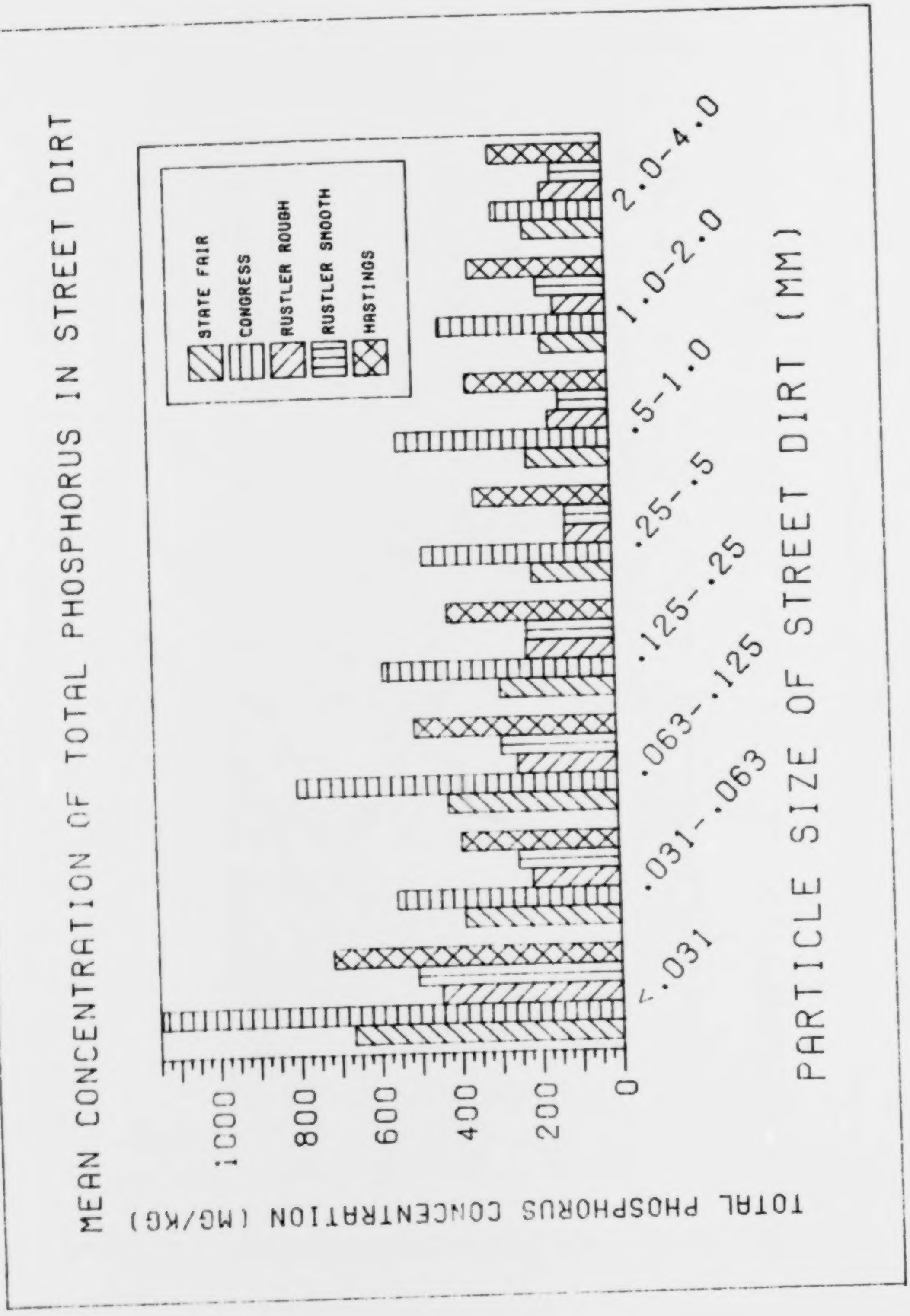

MEAN CONCENTRATION OF TOTAL LEAD IN STREET DIRT
TOTAL LEAD CONCENTRATION (MG/KG)
6000
5000
4000
3000
2000
1000
0
STATE FAIR
CONGRESS
RUSTLER ROUGH
RUSTLER SMOOTH
HASTINGS
<.031
.031-.063
.063-.125
.125-.25
.25-.5
.5-1.0
1.0-2.0
2.0-4.0
PARTICLE SIZE OF STREET DIRT (MM)

FIGURE V.3



MEAN CONCENTRATION OF TOTAL PHOSPHORUS IN STREET DIRT

FIGURE V.4

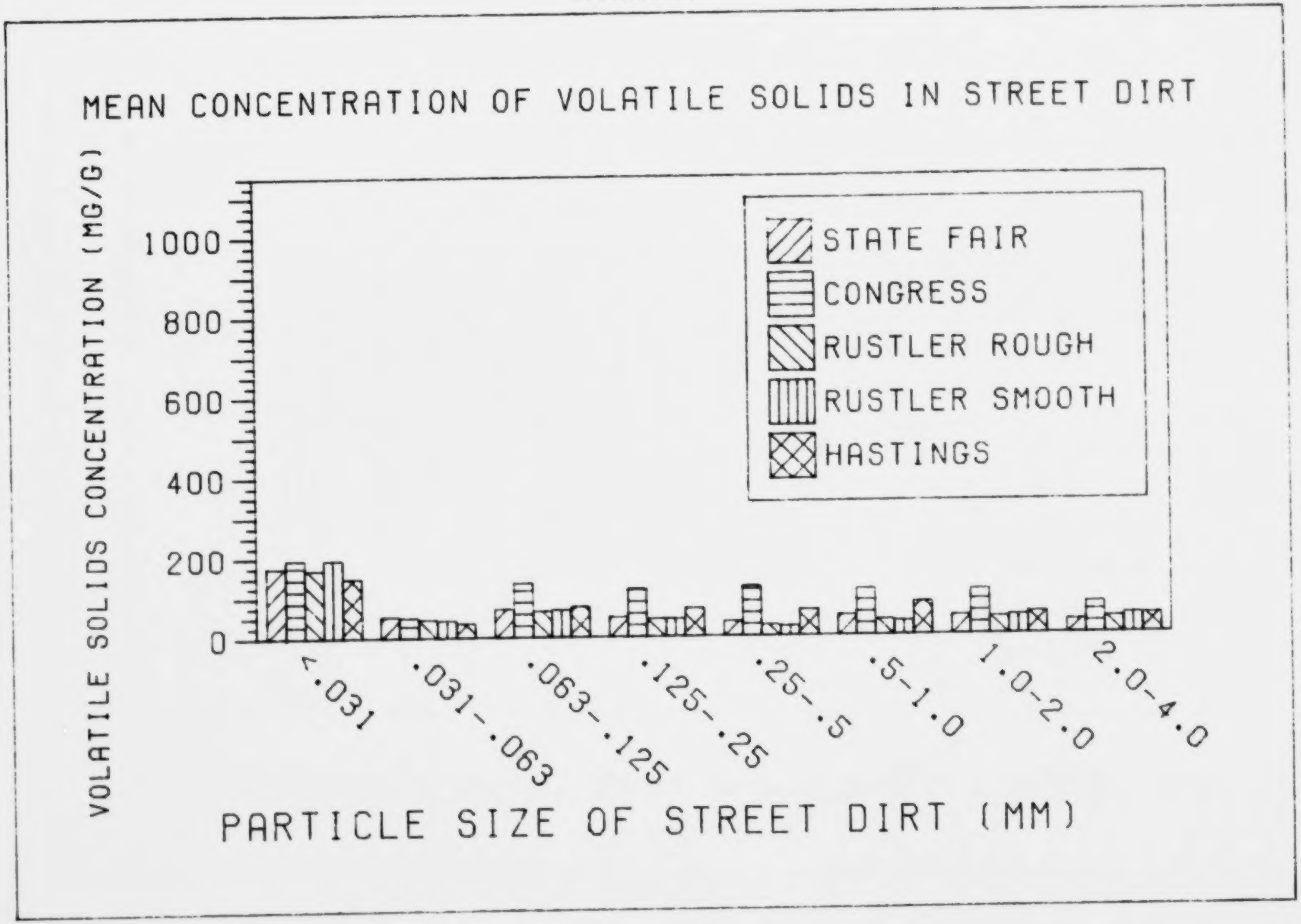
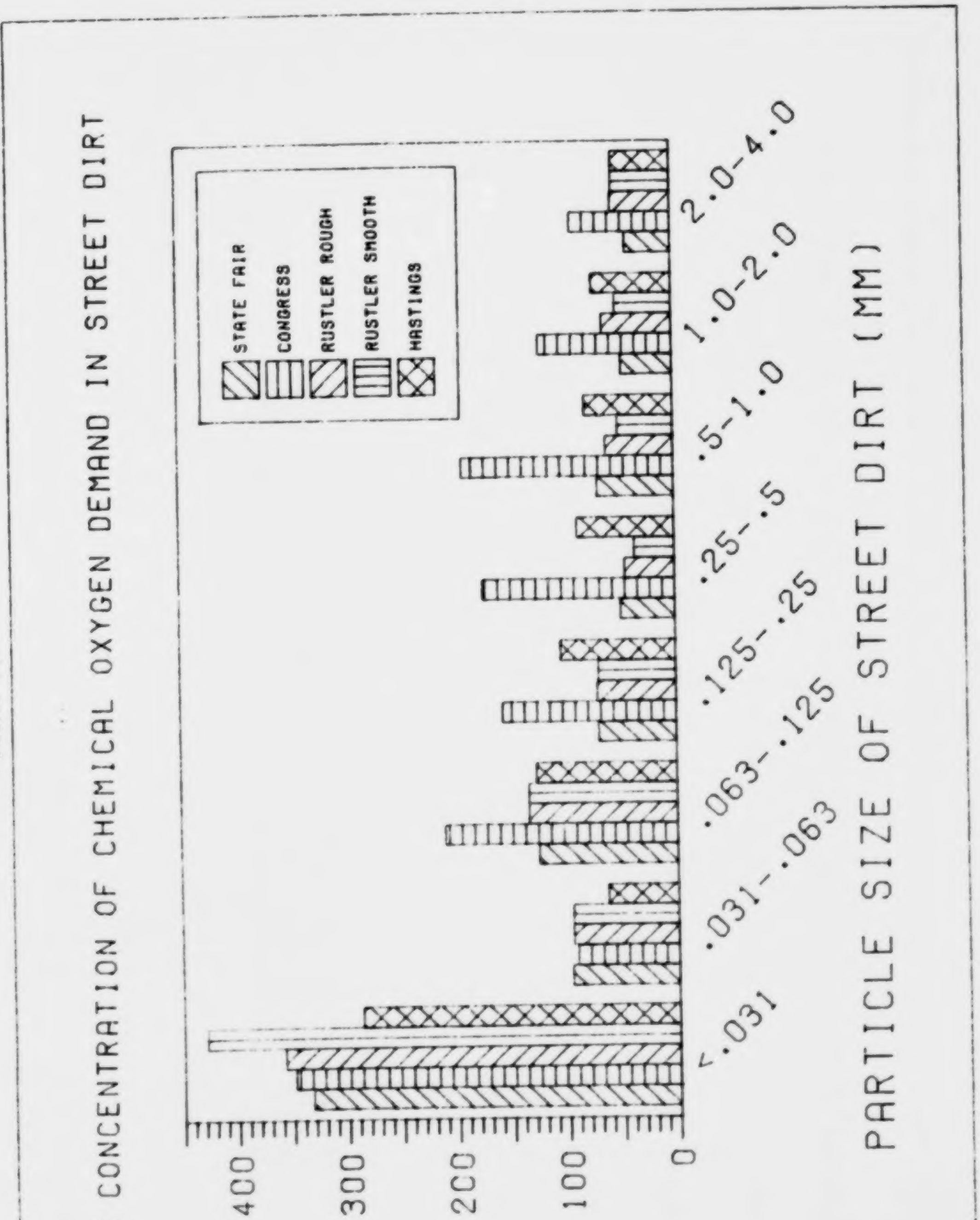

MEAN CONCENTRATION OF VOLATILE SOLIDS IN STREET DIRT
VOLATILE SOLIDS CONCENTRATION (MG/G)
0
200
400
600
800
1000
STATE FAIR
CONGRESS
RUSTLER ROUGH
RUSTLER SMOOTH
HASTINGS
<.031
.031-.063
.063-.125
.125-.25
.25-.5
.5-1.0
1.0-2.0
2.0-4.0
PARTICLE SIZE OF STREET DIRT (MM)

FIGURE V.5



MEAN CONCENTRATION OF CHEMICAL OXYGEN DEMAND IN STREET DIRT

FIGURE V.6

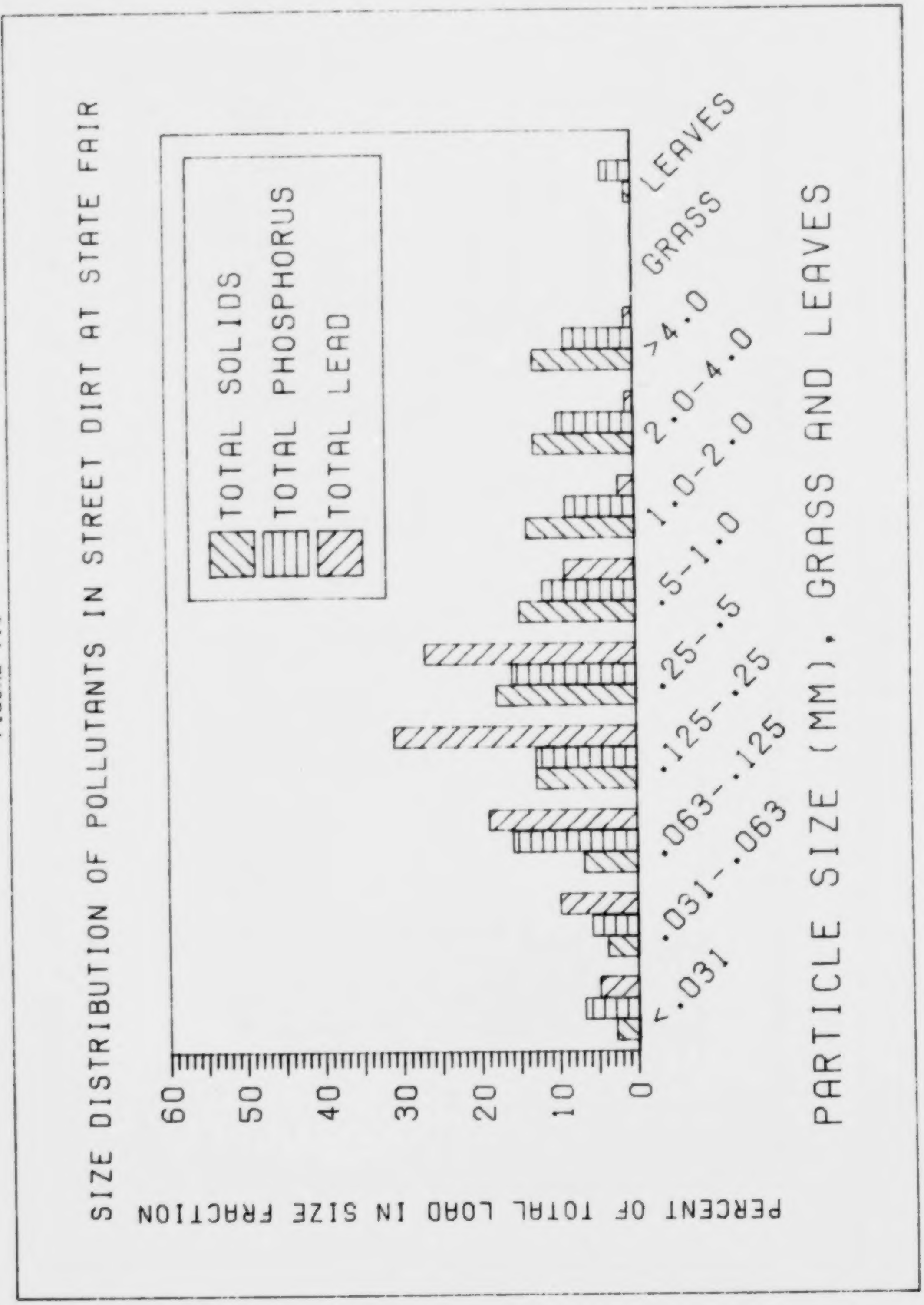
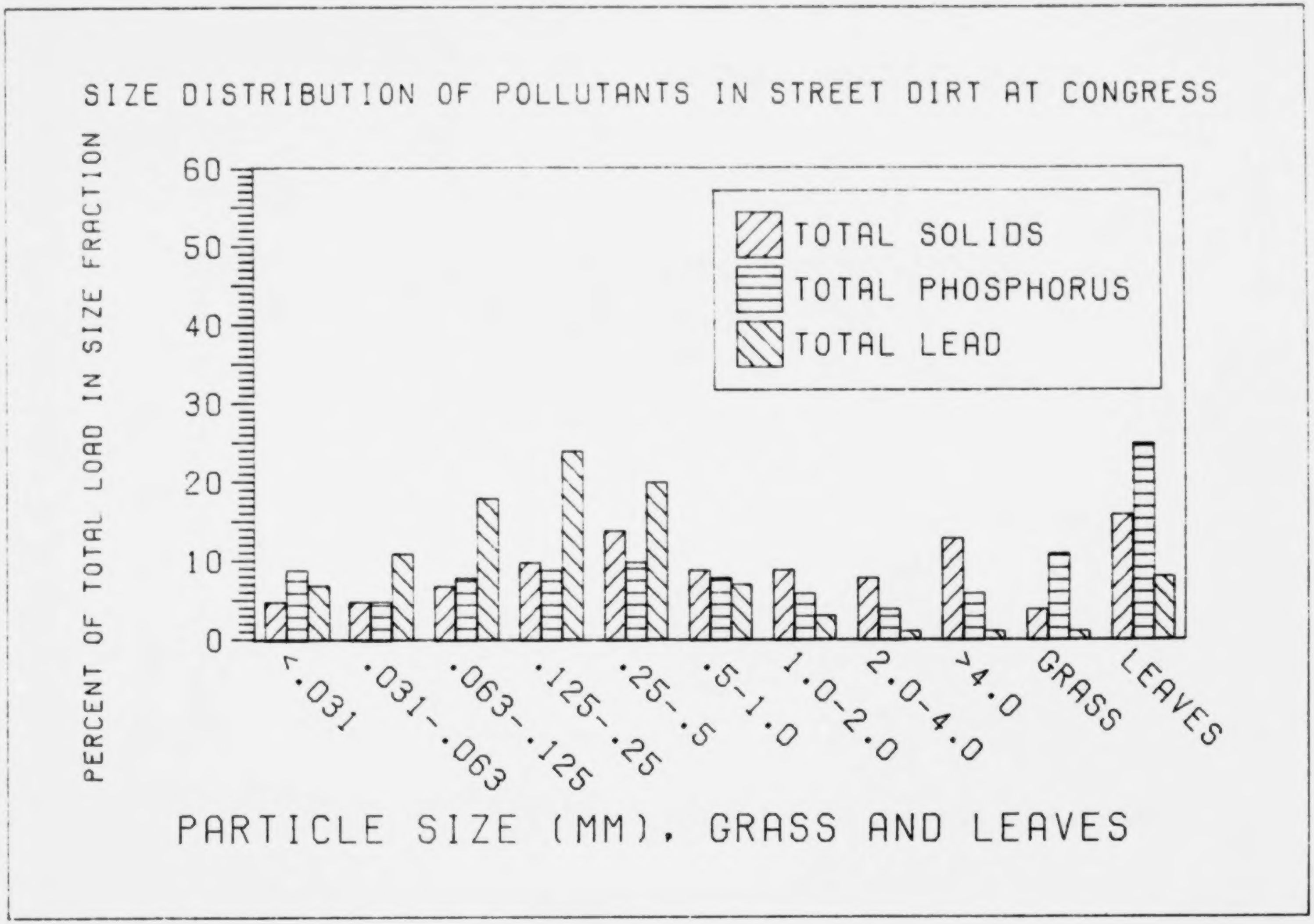

SIZE DISTRIBUTION OF POLLUTANTS IN STREET DIRT AT STATE FAIR
PERCENT OF TOTAL LOAD IN SIZE FRACTION
0
10
20
30
40
50
60
TOTAL SOLIDS
TOTAL PHOSPHORUS
TOTAL LEAD
<.031
.031-.063
.063-.125
.125-.25
.25-.5
.5-1.0
1.0-2.0
2.0-4.0
>4.0
GRASS
LEAVES
PARTICLE SIZE (MM), GRASS AND LEAVES

FIGURE V.7



SIZE DISTRIBUTION OF POLLUTANTS IN STREET DIRT AT CONGRESS

FIGURE V.8

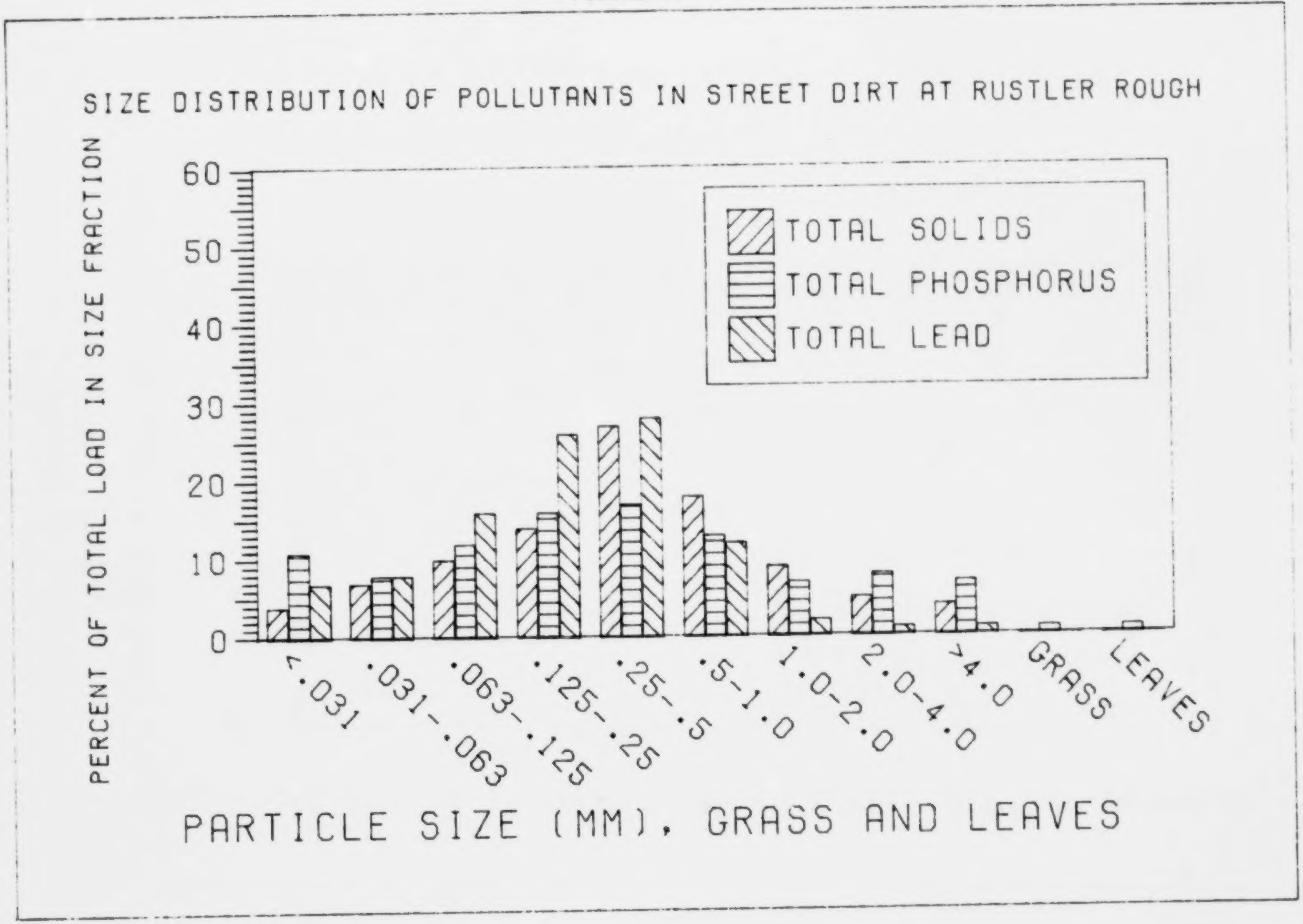
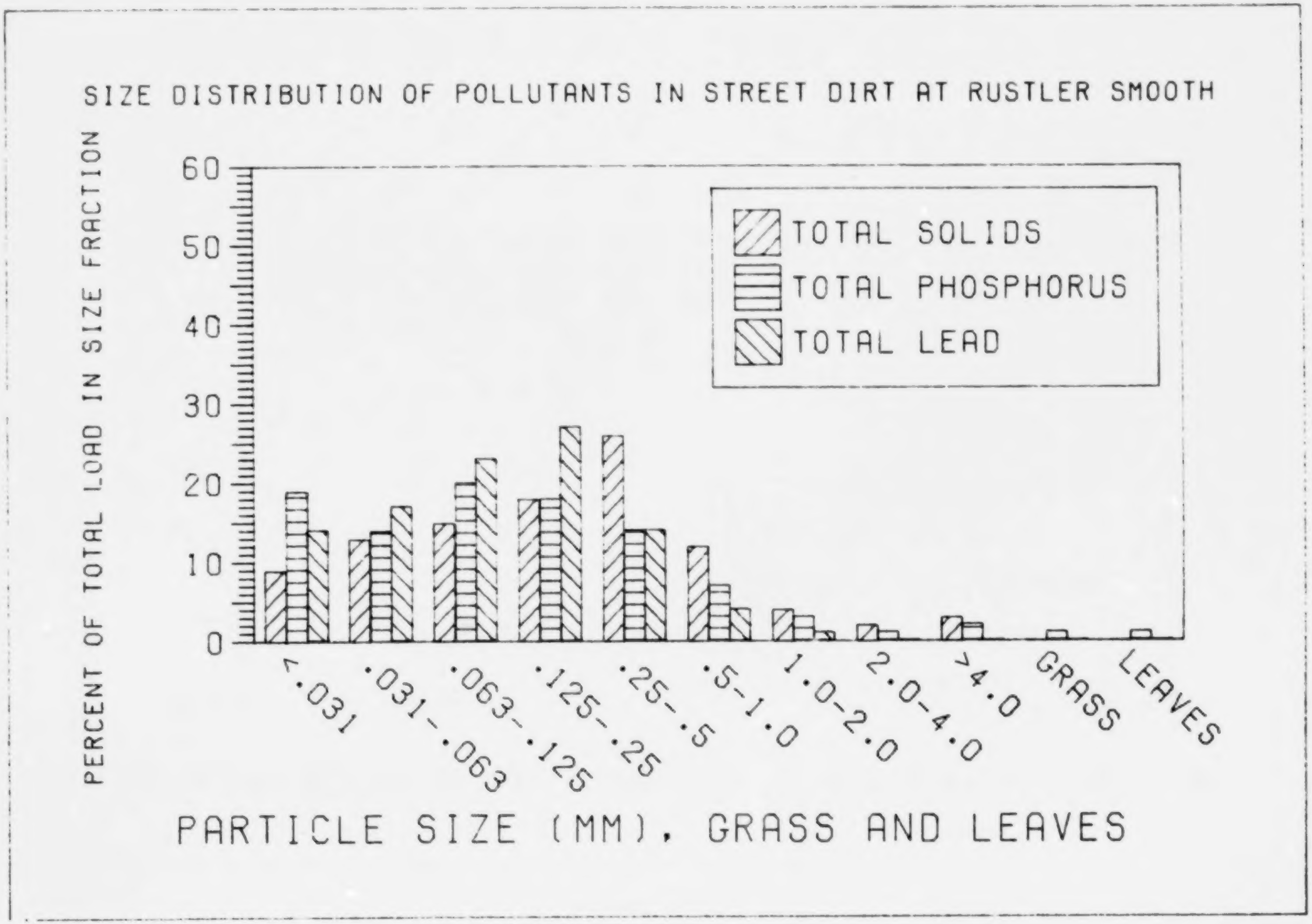
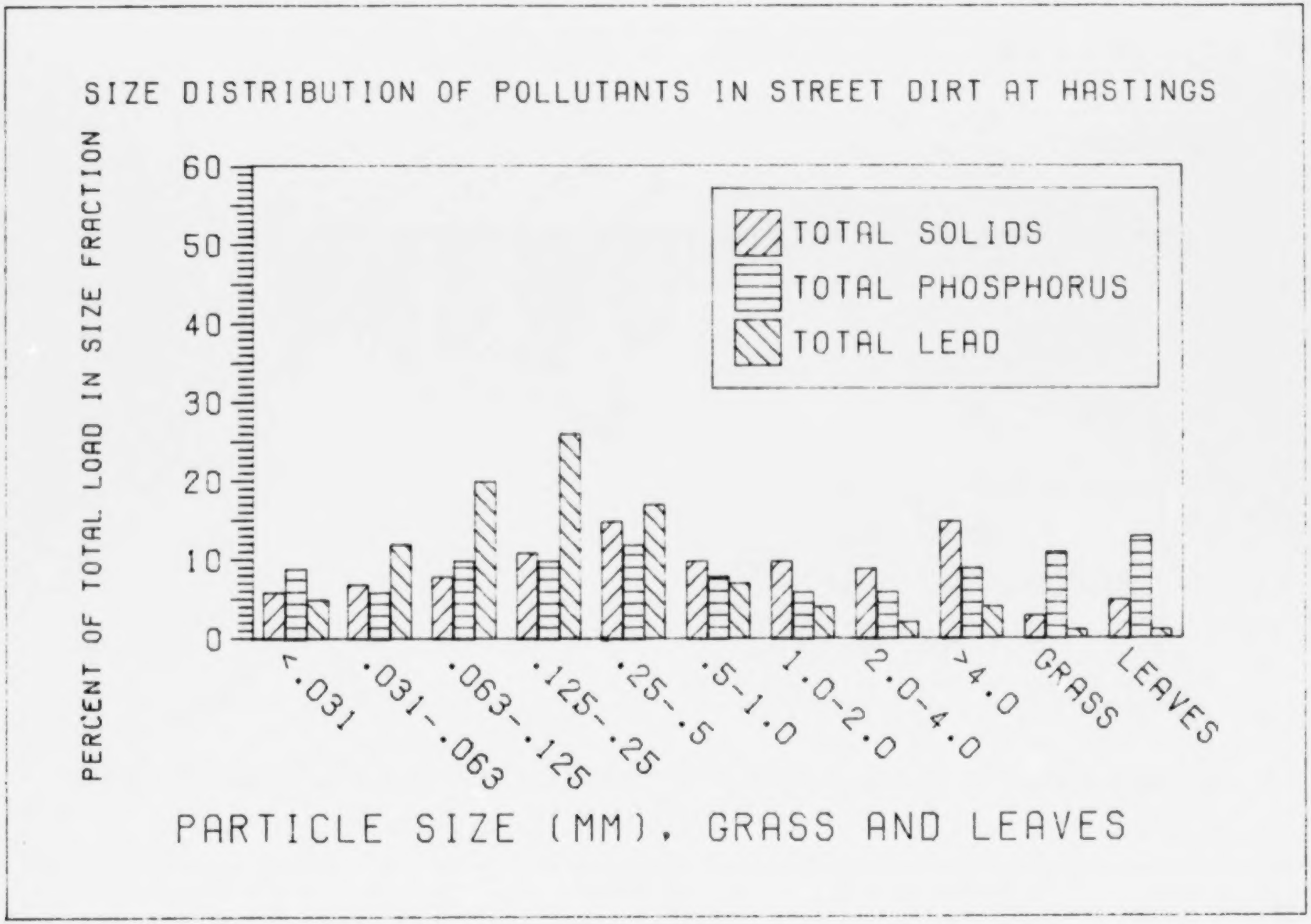

SIZE DISTRIBUTION OF POLLUTANTS IN STREET DIRT AT RUSTLER ROUGH
PERCENT OF TOTAL LOAD IN SIZE FRACTION
60
50
40
30
20
10
0
TOTAL SOLIDS
TOTAL PHOSPHORUS
TOTAL LEAD
<.031
.031-.063
.063-.125
.125-.25
.25-.5
.5-1.0
1.0-2.0
2.0-4.0
>4.0
GRASS
LEAVES
PARTICLE SIZE (MM), GRASS AND LEAVES

FIGURE V.9



SIZE DISTRIBUTION OF POLLUTANTS IN STREET DIRT AT RUSTLER SMOOTH

FIGURE V.10


SIZE DISTRIBUTION OF POLLUTANTS IN STREET DIRT AT HASTINGS
PERCENT OF TOTAL LOAD IN SIZE FRACTION
60
50
40
30
20
10
0
TOTAL SOLIDS
TOTAL PHOSPHORUS
TOTAL LEAD
<.031
.031-.063
.063-.125
.125-.25
.25-.5
.5-1.0
1.0-2.0
2.0-4.0
>4.0
GRASS
LEAVES
PARTICLE SIZE (MM), GRASS AND LEAVES

Street Texture and Condition--

Street texture refers to the roughness or micro-relief of the street surface itself. Street condition refers to the extent of cracks, pot holes or depressions in the street surface. Other factors being equal, streets in good condition have lower loads than streets in poor condition, and streets with smooth surface texture have lower loads than streets with rough texture. To measure relative street surface texture, an outflow meter was used. It consists of a open-ended, weighted plastic tube with a neophrene gasket fitted to its base. The tube is placed on the street, and water is poured in the top. The sample measure is the time it takes for a given volume of water to drain out of the tube. On a smooth street, it takes longer to drain than on a rough street. For a more detailed description of the meter and the sampling method, see Volume III, Chapter III of this report.

Table V.2 indicates average texture sampling times recorded at the study sites. The best indicator of the impact of street texture on street loads is the comparison of Rustler Rough and Rustler Smooth. Their average texture sampling times were 16.5 and 30.6 seconds respectively. At these two sites, all other factors relating to street load are very similar, yet, as depicted in Figure V.11, Rustler Rough has loading levels three to four times greater than Rustler Smooth. At no time did the loads at Rustler Smooth exceed those at Rustler Rough.

Street texture and condition impact street loads because pores and cracks in the streets provide niches for contaminants to lodge in, and reduce the removal potential of wind, rain and street sweeping. Further, streets in poor condition or ones that are deteriorating may themselves be sources of contaminants.

Seasonal Variations In Street Surface Contaminant Loadings

Figures V.12-20 depict street surface total solids loads at State Fair, Congress and Hastings during the spring, summer and fall of 1981. In addition, Table V.3 lists average seasonal street loads over the duration of the study. Several observations can be made about these graphs and this table.

First, the street loads observed in this study appear to be among the lowest ever reported in the United States. Sartor and Boyd (1972), for new medium density residential areas in nine U.S. cities, reported a mean street loading rate of 121 grams per curb meter. Milwaukee was one of the nine cities included within that group, itself with a mean loading rate of 79 grams per curb meter. Pitt (1983), drawing from several prior studies, reported initial street loading values that ranged from 37 to 704 grams per curb meter. Closer in time and location, Terstriep et. al. (1982) reported mean street loads of 40 and 47 grams per curb meter for two residential areas being swept once per week, and 94 and 247 grams per curb meter for two commercial areas also swept once per week.

TABLE V.2

STREET SURFACE TEXTURE COMPARISON

Site	Street Description	Average Sample Time* (seconds)
State Fair	Oil and screen	7.1
State Fair	Asphalt, side street, poor conditions	8.9
State Fair	Asphalt, side street, moderate conditions	12.7
State Fair	Asphalt, side street, moderate traffic	96.9
State Fair	Asphalt, main street, very heavy traffic	56.5
Congress	Asphalt, poor to moderate condition	15.7
Rustler Rough	Asphalt, poor condition	16.5
Rustler Smooth	Asphalt, moderate to good condition	30.6
Hastings	Concrete, good condition	24.1

* Sample time is the time required for a unit amount of water to drain from an outflow meter.

Table V.3

MEAN SEASONAL LOADINGS OF STREET SURFACE CONTAMINANTS[*]

	Annual	March-April	May-September	October-November
State Fair				
Total Solids	82.0	383.8	60.3	51.1
Volatile Solids	3.9	16.1	2.9	3.3
COD	6.2	27.3	4.5	4.6
Total Phosphorus	18.5	75.1	14.0	14.2
Total Lead	148.1	293.5	134.9	141.0
Congress				
Total Solids	31.8	37.3	28.3	35.3
Volatile Solids	8.5	4.7	5.3	22.2
COD	9.9	6.8	6.6	23.3
Total Phosphorus	22.4	16.3	17.6	42.8
Total Lead	31.8	34.8	31.9	26.2
Hastings				
Total Solids	15.4	19.7	13.3	19.0
Volatile Solids	2.1	1.4	1.4	5.3
COD	2.6	2.0	1.8	5.9
Total Phosphorus	7.5	7.3	6.1	13.1
Total Lead[+]	19.9	+	+	+
Rustler Rough				
Total Solids	23.0	34.9	21.7	19.2
Volatile Solids	1.1	1.7	1.0	0.9
COD	1.9	2.8	1.8	1.7
Total Phosphorus	4.2	5.1	4.3	3.6
Total Lead[+]	20.5	+	+	+
Rustler Smooth				
Total Solids	5.1	6.0	4.7	5.5
Volatile Solids	0.3	0.3	0.2	0.3
COD	0.5	0.6	0.5	0.6
Total Phosphorus[+]	1.1	+	+	+
Total Lead	6.4	+	+	+

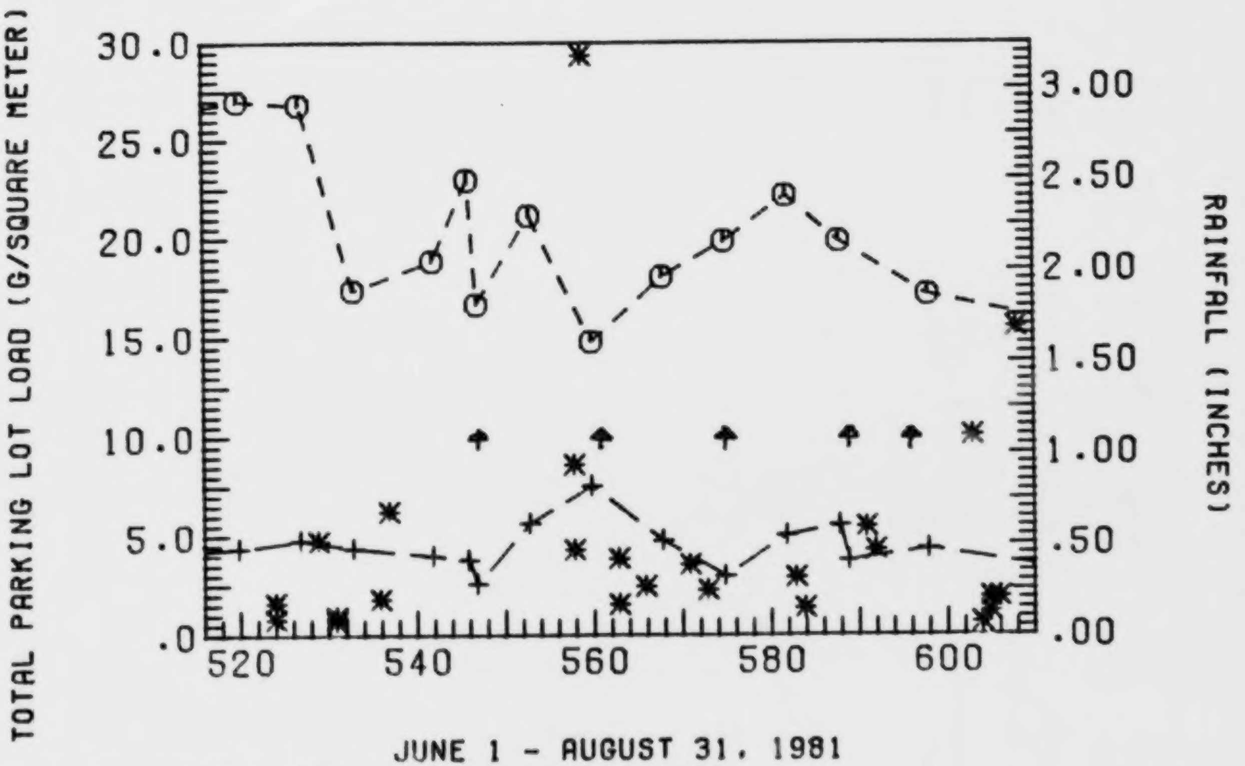
---

[*] Unit are in weight/street surface area. Weights are in grams for Total Solids, Volatile Solids and COD, and mg for Total Phosphorus and Total Lead. Areas are in curb meters for State Fair, Congress and Barbank, and square meters for Rustler Rough and Rustler Smooth.

[+] There was no statistically significant difference among seasonal loading values for these parameters (alpha = .05).

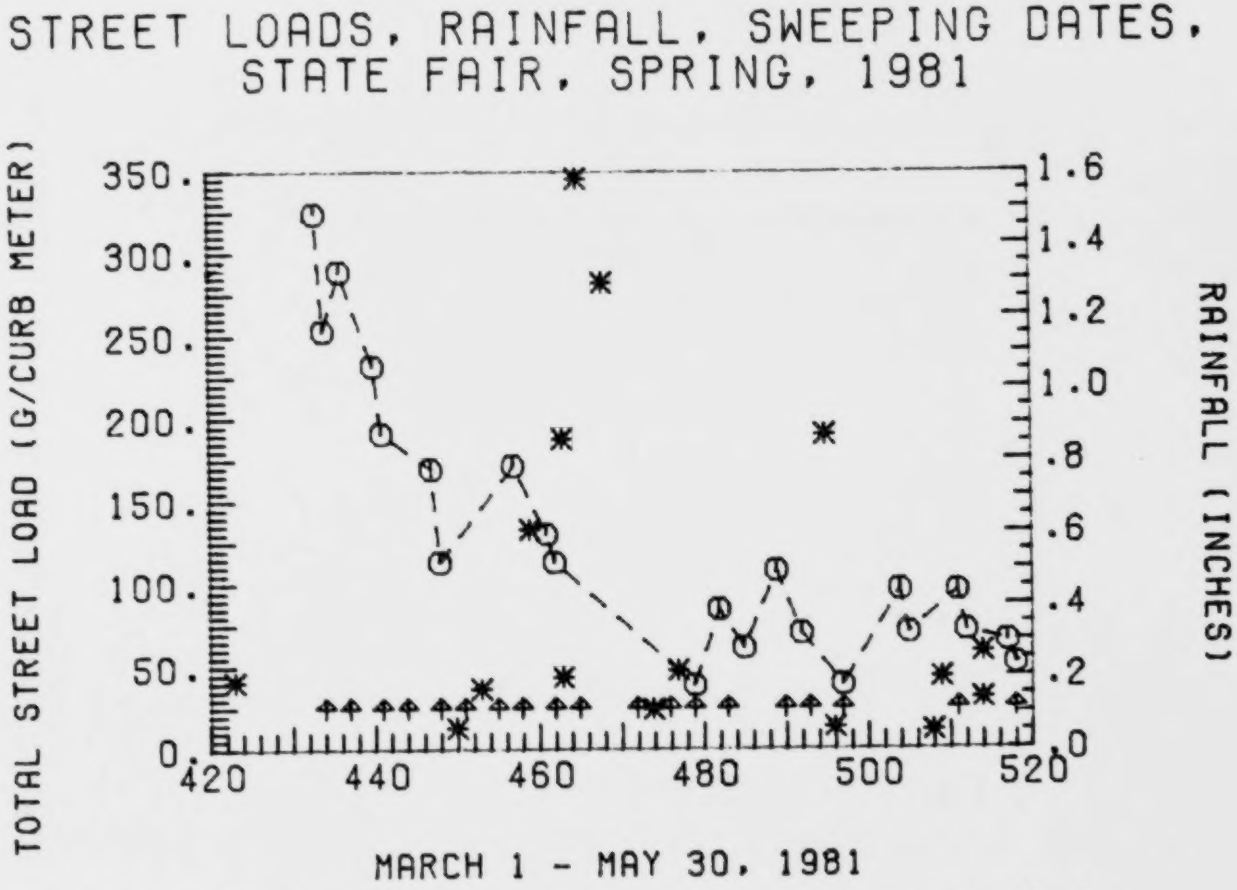
FIGURE V.11

PARKING LOT LOADS, RAINFALL, SWEEPING DATES,
RUSTLER, SUMMER 1981



Asterisks are rainfalls, arrows are sweeping dates.
Circles are loads at Rustler Rough, crosses are loads at Rustler Smooth.

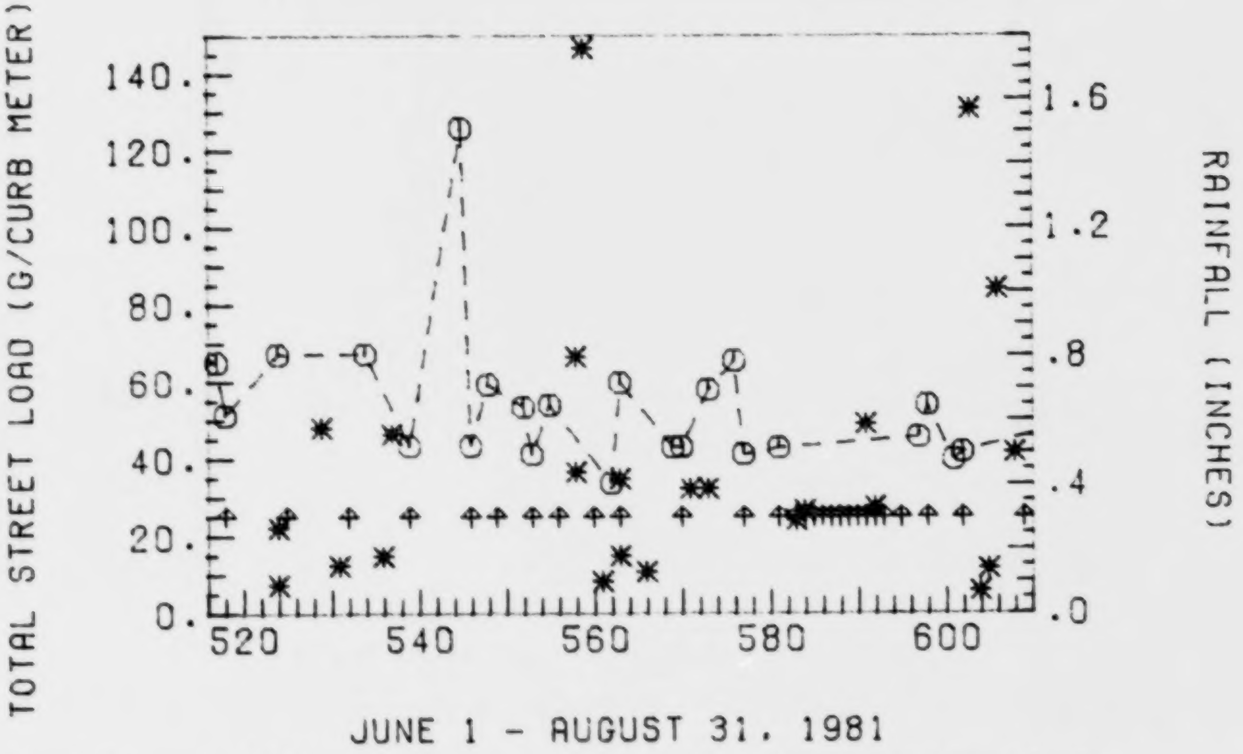
FIGURE V.12



STREET LOADS, RAINFALL, SWEEPING DATES, STATE FAIR, SPRING, 1981

Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

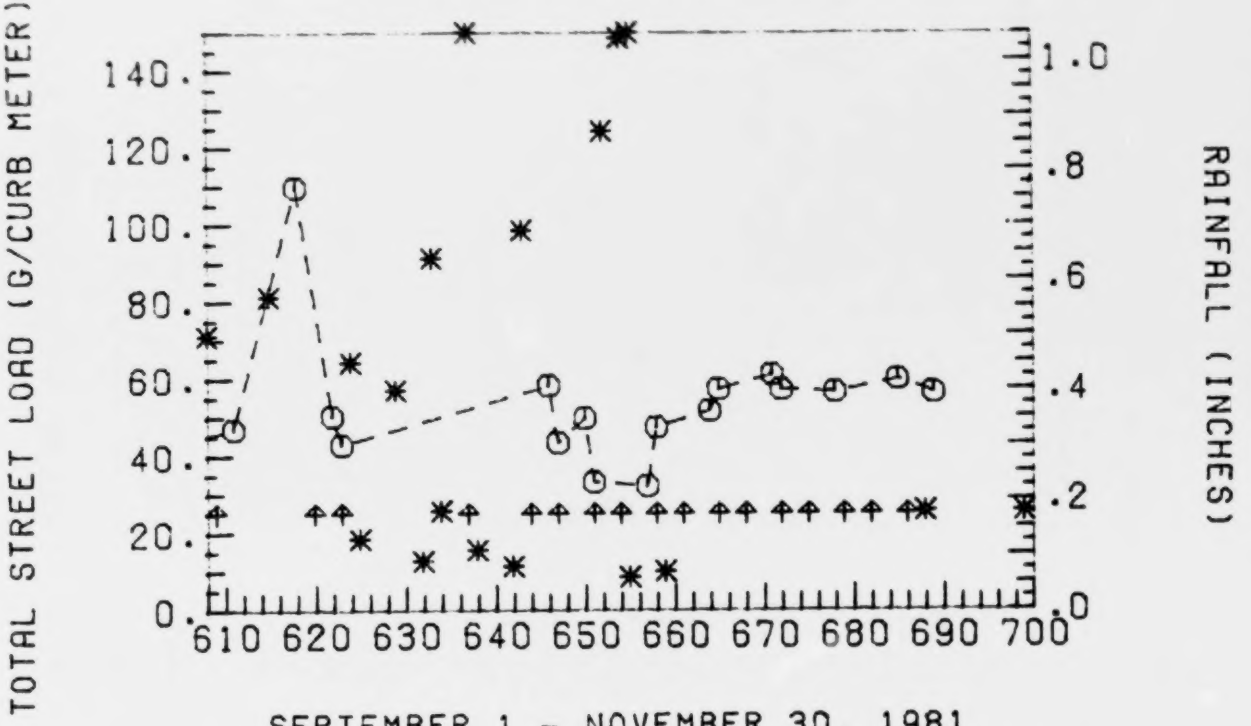
FIGURE V.13


STREET LOADS, RAINFALL, SWEEPING DATES,
STATE FAIR, SUMMER, 1981

Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

FIGURE V.14

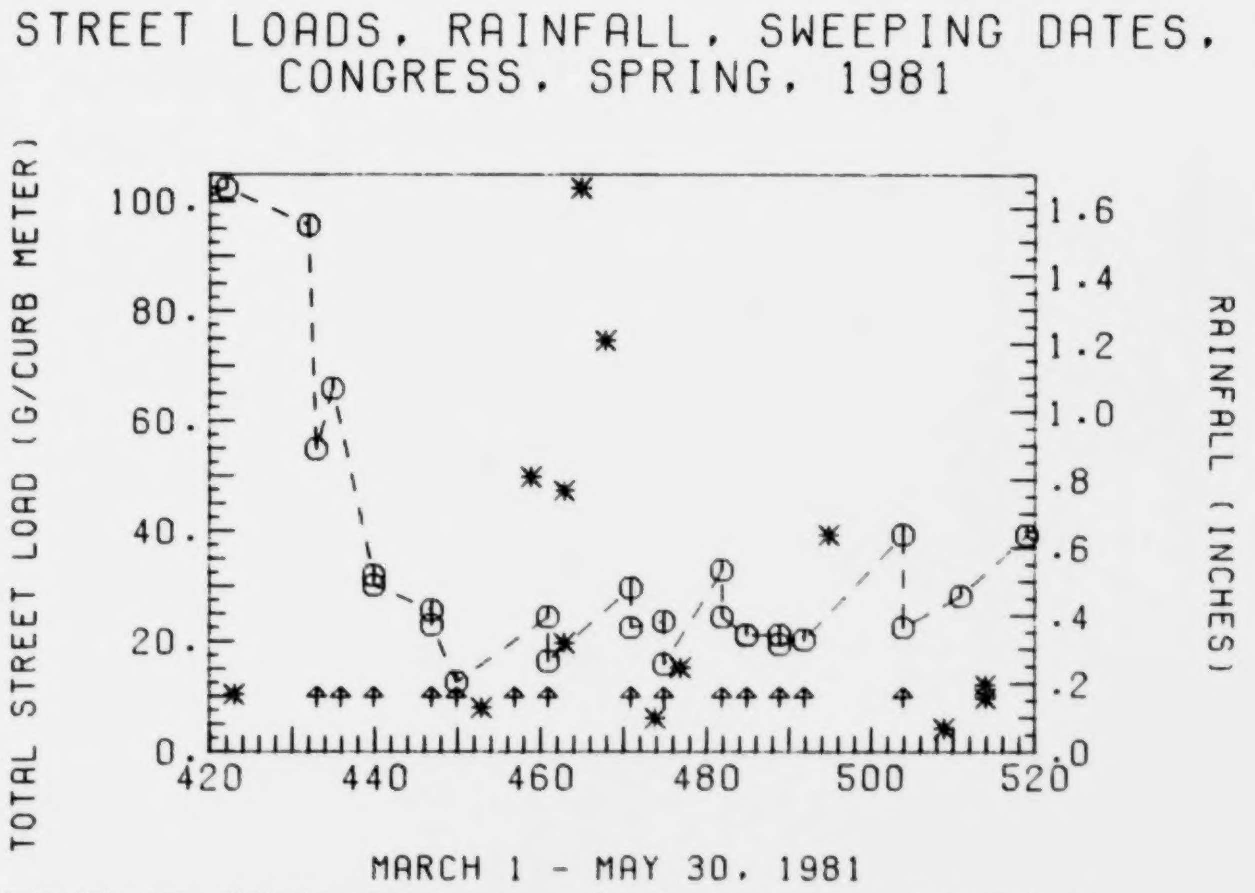
STREET LOADS, RAINFALL, SWEEPING DATES,
STATE FAIR, FALL, 1981



SEPTEMBER 1 - NOVEMBER 30, 1981

Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

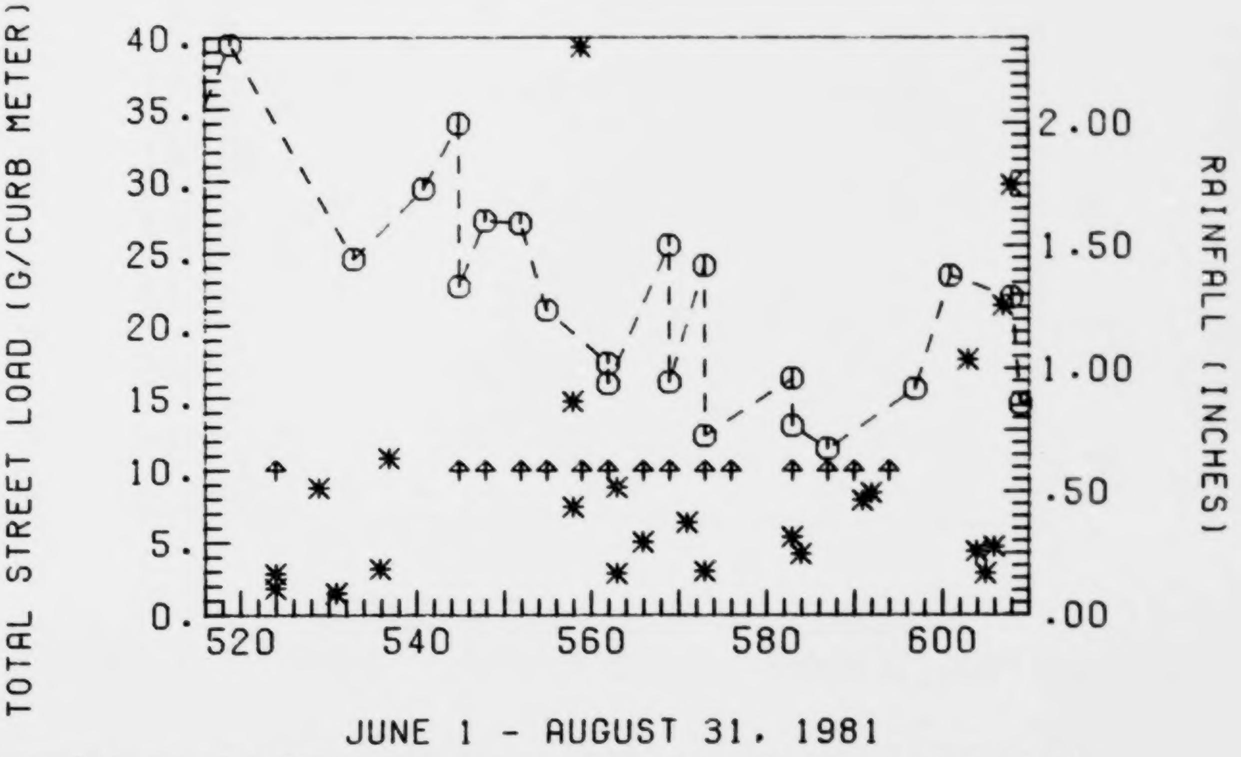
FIGURE V.15



Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

FIGURE V.16

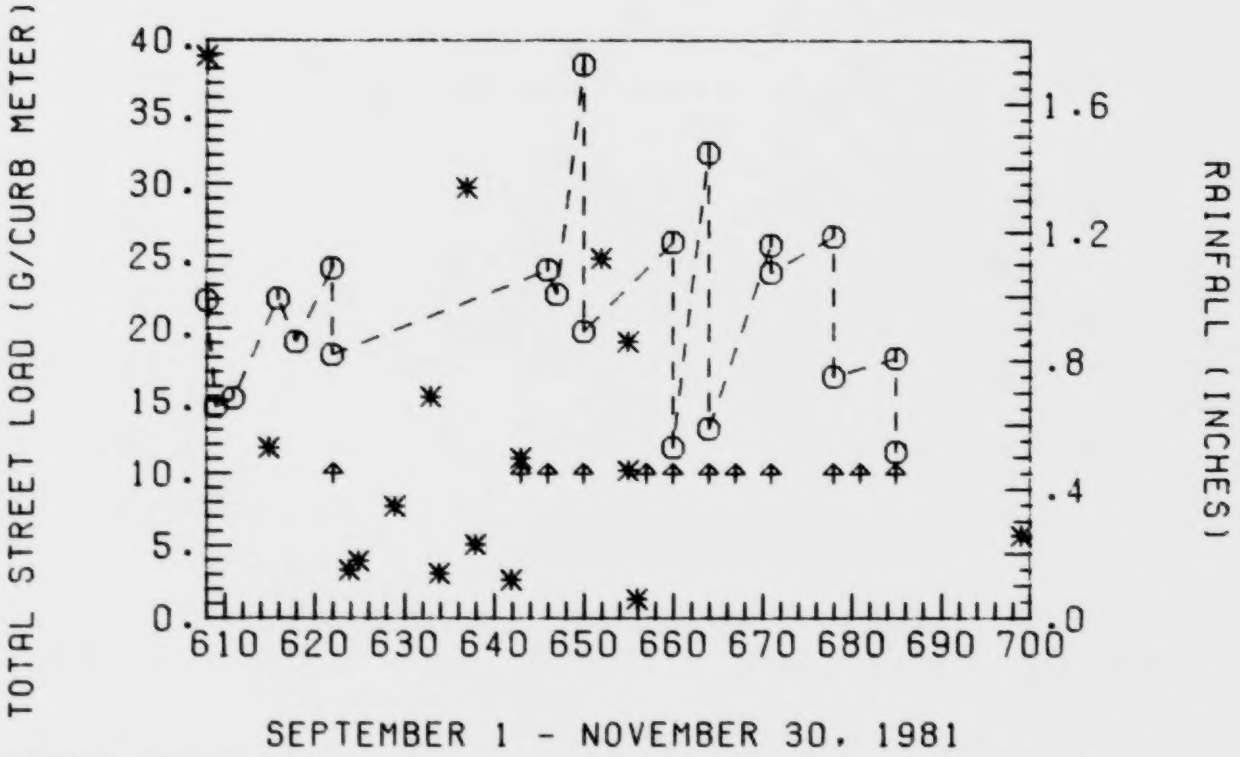
STREET LOADS, RAINFALL, SWEEPING DATES, CONGRESS, SUMMER, 1981



Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

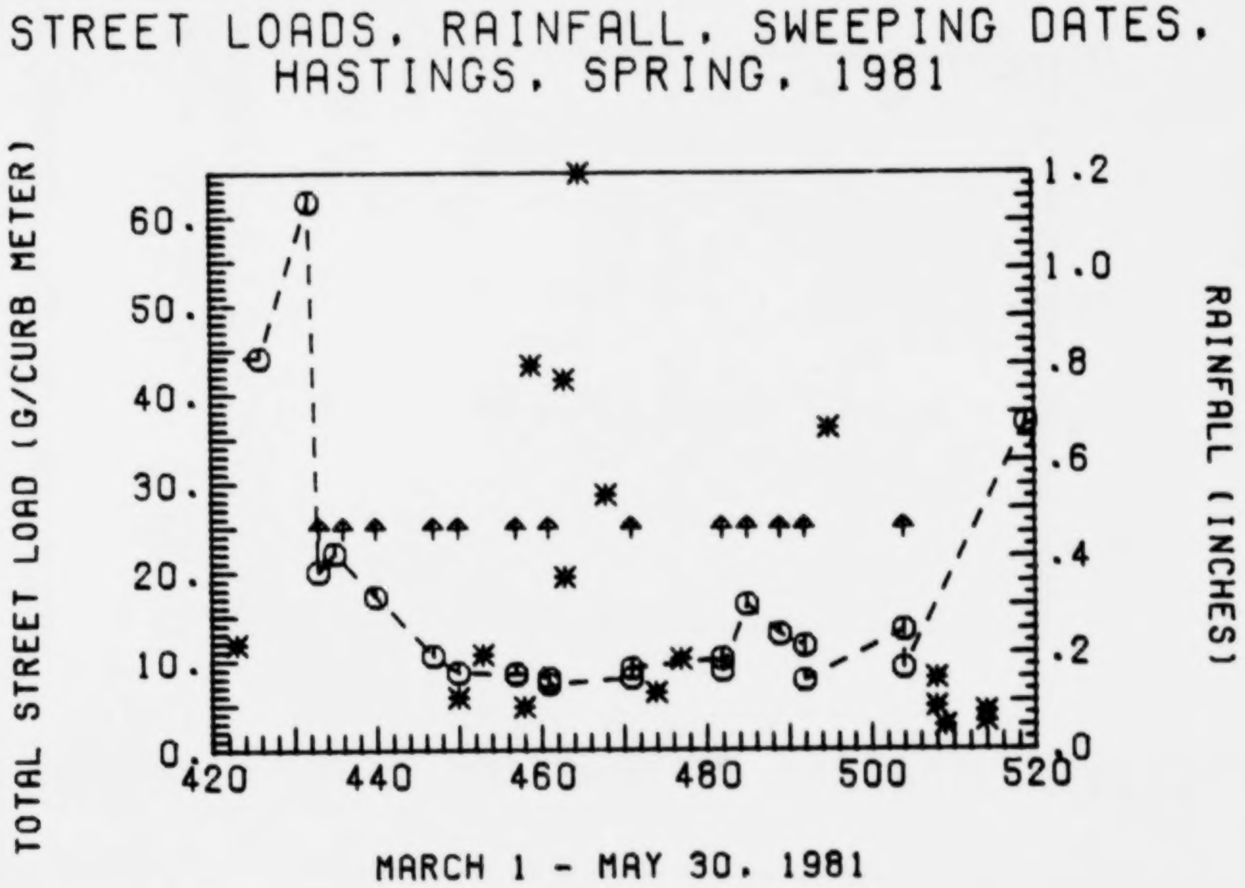
FIGURE V.17

STREET LOADS, RAINFALL, SWEEPING DATES,
CONGRESS, FALL, 1981



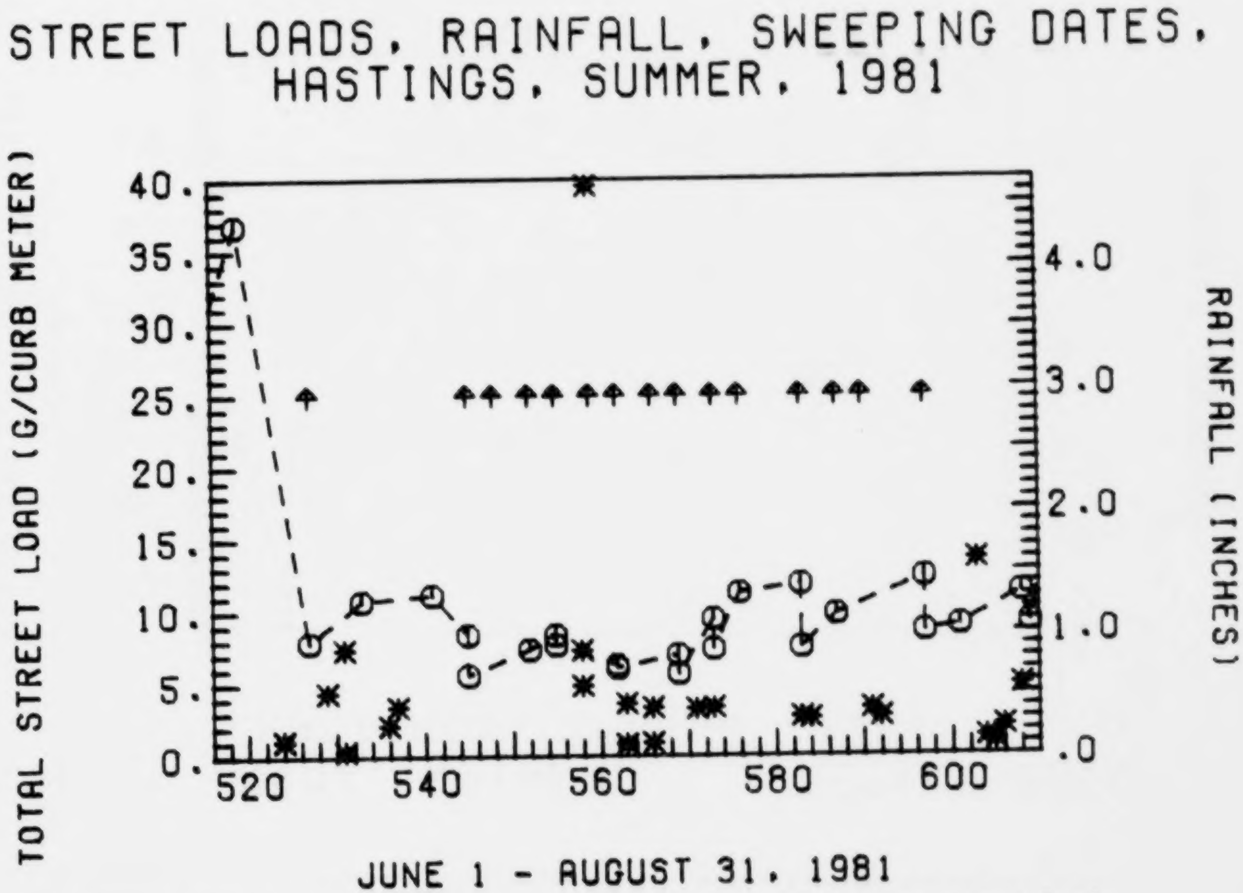
Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

FIGURE V.18



Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

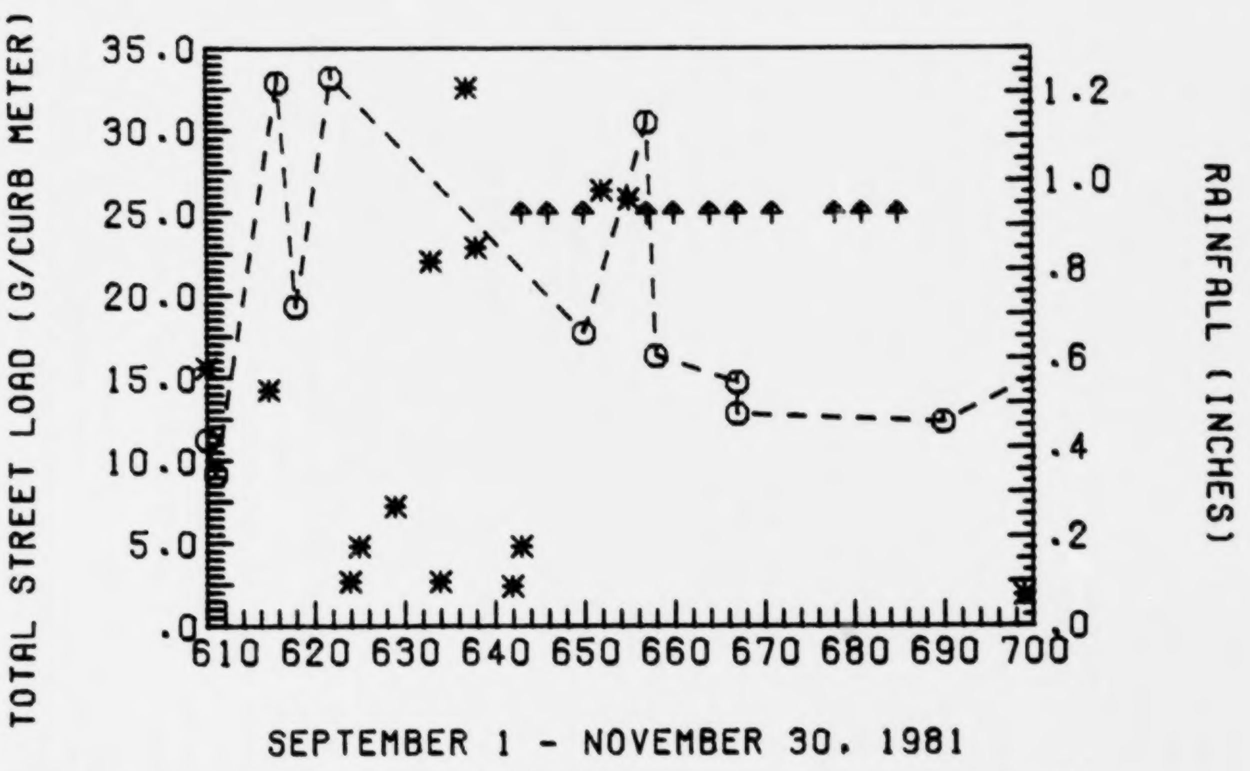
FIGURE V.19



Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

FIGURE V.20

STREET LOADS, RAINFALL, SWEEPING DATES,
HASTINGS, FALL, 1981



Asterisks are rainfalls, arrows are sweeping dates, circles are street loads.

Street loads are higher in the spring and fall. In the spring, residue of winter street sanding operations remain until they are eventually swept, washed or blown away. In the fall, leaf drop is evident. From late spring to early fall, loads generally vacillate within a distinct and unique range at each station. These ranges are roughly from 5-15, 15-40, and 40-80 grams per curb meter at Hastings, Congress and State Fair respectively, and from 3-7 and 15-25 grams per square meter at Rustler Smooth and Rustler Rough respectively. In each case, the upper bound is roughly two to three times higher than the lower bound. Seldom does the street load drop below the lower bound, or rise above the upper bound.

The lower bound on the street loads suggest that there is a minimal 'reservoir' of material on the streets of each site. This reservoir of material is related to street surface texture and condition. The reservoir does not seem to be significantly diminished by either frequent rainfalls or street sweeping. The relative stability of this reservoir raises questions about the availability of these materials to street sweeper removal, wind resuspension, or rainfall-washoff.

Variations in street loads over time are a function of daily inputs and outputs. Input processes include materials blown in by wind, tracked in by, emitted from, or washed off of cars, deposited by animals, settled out of the air, washed in by rainfall, abraided from street surfaces, or discarded by humans. Output processes include materials blown out by wind or turbulence of passing cars, picked up by sweepers or washed out by rainfall. The following subsections of this chapter discuss the accumulation and rainfall washoff of street surface contaminants. Street sweeper removal is discussed separately in Chapter VI., IMPACTS OF STREET SWEEPING ON URBAN STORMWATER QUALITY.

Accumulation Rates Of Street Surface Contamination

In the absence of street sweeping or rainfall, daily accumulation of contaminants is a function of the combined inputs, minus that which is blown away. As more materials accumulate on the street, more can be resuspended and blown away by a given force of wind. Under constant wind and constant input conditions, and if left to proceed indefinitely, materials would theoretically accumulate to a point where the daily output equaled the daily input, and equilibria would be reached. Such uniform conditions however do not exist. Wind and traffic conditions fluctuate constantly, and discrete events such as high wind, rainfall and street sweeping regularly occur to suddenly change contaminant input and/or output.

Several input/output processes were measured in this study, including atmospheric deposition, street sweeper removal and rainfall washoff. Several input/output processes could not be measured directly, such as wind related deposition and resuspension. In an effort to develop overall accumulation functions, streets at the test sites were monitored at frequent intervals throughout the study period. Intervals between points of sampling when there was no rain greater than a tenth of an inch, and no street sweeping, were designated as accumulation periods. For example, if the streets at Congress were sampled on the 10th, 14th and 17th of May, and if there had not been any street sweeping nor rains greater than .1 inches during that time, then there would be three accumulation periods (10-14, 14-17, and 10-17). Because of the frequent rainfalls and street sweeping in the test areas, the longest accumulation monitored was 20 days. Most were much shorter than this.

There were 142 total accumulation periods monitored. There is considerable scatter in the data at each site, which is thought to be mostly a function of the large error associated with each of the samples ($\pm$ 25 percent) relative to the small increase in street loads of a typical accumulation period (generally less than five to ten percent of the average load on the street over that time).

Various literature sources have proposed that accumulation rates decrease as the load on the street increases (Sartor and Boyd, 1974; Shaheen, 1975; Pitt, 1979). Their basic tenet was that, as material accumulates on the street, more is available to be blown away by wind or passing traffic. Shaheen (1975) drew accumulation curves plotting the load on the street since time of last cleaning. However, loads on the street are not uniform following street cleaning, so there is not a consistent starting point for such a relationship. Secondly, if the theory is correct, accumulation rates are a function of street loads and not of time. Therefore, a relationship was sought not between time and daily accumulation rates, but between loads on the street and daily accumulation rates. Stepwise multiple regression was used for this analysis. Independent variables included the average load on the street during each accumulation period, the natural log, square root and square of this average load, and the reciprical of each of the above. The dependent variable was the average daily accumulation rate for each accumulation period. Stepwise regression attempted to define a relationship between any one or combination of the independent variables and the dependent variable. In no case was a statistically significant relationship found. The data from this project does not support the theory of diminishing accumulation rates with increasing street loads in the range of street loads observed at the Milwaukee study sites. Diminishing accumulation rates were observed by Pitt (1979) for study areas exhibiting street loads that were up to eight times higher than the average street load observed in Milwaukee.

Table V.4 gives median accumulation rates for total solids (exclusive of grass and leaves) for three different particle sizes of street dirt. At most sites, there is little accumulation in the coarse size range (greater than 2.0 mm), and little difference in the accumulation rates between the fine and medium size ranges (less than .125, and .125-2.0 mm respectively). At State Fair, where there is over 15,000 cars per day, there is a predominance of accumulation in the medium size range, and significant amounts in both the fine and coarse ranges. If all of the accumulation at State Fair is assumed to be traffic induced, then traffic related accumulation rates would be on the order of .2 mg per curb meter per car.

Table V.4

STREET SURFACE CONTAMINANT ACCUMULATION RATES, BY PARTICLE SIZE

Station	Number of Comparisons	Median Accumulation Rate*			
		<.125 mm	.125-2.0 mm	> 2.0 mm	Total**
State Fair	22	.67	2.47	.66	3.45
Congress	27	.08	.15	-.06	-.05
Rustler Rough	30	.16	.18	.00	.36
Rustler Smooth	39	.04	.02	-.01	.04
Hastings	24	.06	.06	.03	.28

* Rates are in g/curb m/day at State Fair, Congress and Hastings, and g/m^2/day at both Rustler sites.

** Total is exclusive of grass and leaves.

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Besides traffic, another major source of street surface pollutants is atmospheric deposition or dryfall. Atmospheric dryfall was measured at eight different sites (see subsequent discussion in this chapter). Average atmospheric total solids deposition rates can be expressed in grams per square meter per day. Accumulation rates at the Rustler sites are already in those units. By including average street widths at State Fair, Congress and Hastings (45, 30 and 30 feet respectively), accumulation rates at these sites can be converted to these units. Table V.5 compares average accumulation rates at the study sites with average atmospheric deposition rates at the nearest atmospheric sites. At Rustler Smooth and Hastings, the average rates are about equal. At State Fair, the accumulation rate is much higher than the deposition rate, presumably attributable to the high traffic there. Congress and Rustler Rough are anomalous. Accumulations at Rustler Rough may be high due to the deteriorating asphalt.

High winds were initially thought to significantly diminish street loads. While they are capable of resuspending and removing materials from street surfaces, they can also import materials suspended off of other areas. An attempt was made to determine the impact of wind on the accumulation rates. The accumulations were divided into two groups: those that included periods of high wind (here defined as more than 20 miles per hour for more than 3 hours) and those that did not. Of the 142 total accumulations, 62 of them included periods of high winds, and 80 of them did not. Table V.6 presents the results of this analysis. At State Fair and Congress, high winds tend to cause a net increase in the accumulation rates, while in the parking lots, they cause a net decrease. At Hastings, there is little impact. State Fair has multi-story buildings with few open spaces. Congress has mature trees with small yards. The parking lots on the other hand have large, flat exposed surfaces. Hastings has one-story houses, big yards and small trees. and is perhaps mid-way between the two pairs with respect to relief. The relief of an area (trees and buildings) appears to effect the shear strength of the wind at the ground surface, and the ability of the wind to maintain particles in suspension. According to this theory, in wind sheltered areas, wind should deposit more than it resuspends, and in exposed areas, it should resuspend more than it deposits. The data supports this theory, with the exception of the coarse particles at Congress, which appear to be resuspended by the wind.

A related component of this study was the development of a model to estimate street load and washoff. A simple model called SLAW (Street Load and Washoff) was developed to do this (see Chapter VI of this volume and Volume III for more detailed discussions of SLAW). The model uses average net daily accumulation rates and does not incorporate deposition and resuspension rates separately. It also uses observed site specific street sweeper removal and rainfall washoff data. Net daily accumulation rates are the one set of variables used to calibrate the model to the observed total loads and individual particle size distributions. The accumulation rates measured in this project versus those calibrated with SLAW are given in Table V.7. There is reasonable agreement between the two at State Fair, whereas at Hastings, the calibrated rate is twice the monitored value, while Congress is, as before, anomolous.

Table V.5

STREET SURFACE CONTAMINANT ACCUMULATION RATES VS. ATMOSPHERIC DRY DEPOSITION RATES

Street Surface Contaminant Monitoring		Atmospheric Dry Deposition Monitoring	
Site	Median Accumulation Rate*	Nearest Sites	Mean Total Solids Dry Deposition Rate*
State Fair	.50	SED HQ, Wood, West Allis, Oil Gear	0.71
Congress	-.01	Appleton Ave., Telephone Co.	.062
Rustler Rough	.36	Appleton Ave., Telephone Co.	.062
Rustler Smooth	.04	Appleton Ave., Telephone Co.	.062
Hastings	.07	St. Bernadette, DPW	.055

* Rates are in g/m^2/day

Table V.6

STREET SURFACE CONTAMINANT ACCUMULATION RATES* UNDER CALM AND WINDY CONDITIONS**

Site	N		Median Accumulation Rate of Various Particle Sizes+							
			<.125 mm		.125-2.0 mm		>2.0 mm		Total	
	Calm	Windy	Calm	Windy	Calm	Windy	Calm	Windy	Calm	Windy
State Fair	12	10	-.14	.94	1.22	2.72	.02	1.16	2.50	4.58
Congress	21	6	.00	.23	.08	.37	.02	-.12	-.05	.33
Rustler Rough	14	16	.22	.15	.39	-.01	.03	-.01	.52	.10
Rustler Smooth	18	21	.06	.03	.13	.01	-.02	.00	.10	.03
Hastings	15	9	.27	.03	.02	.14	-.05	.16	.32	.24

* Accumulation rates are in g/curb m/day at State Fair, Congress and Hastings, and in g/m^2/day at the Rustler sites.

** Windy accumulations include any accumulation period with winds of more than 20 MPH for more than 3 hours. Those that did not were calm accumulations.

+ Total is exclusive of grass and leaves.

TABLE V.7

MONITORED VS. CALIBRATED ACCUMULATION RATES*

	Median Monitored Rate				Calibrated Rate Used With SLAW Model			
	.125 mm	.125-2.0 mm	2.0 mm	Total	.125 mm	.125-2.0 mm	2.0 mm	Total
State Fair	.67	2.47	.66	3.45	.6	1.8	.01	2.41
Congress	.08	.15	-.06	-.05	.4	.75	.3	1.45
Hastings	.06	.06	.03	.28	.3	.35	.05	.70

*grams per curb meter per day

Rainfall Washoff Of Street Surface Contaminants

One important component of this study was an evaluation of street surface pollutant washoff by rainfall. While recognizing the importance of this effort, several problems hampered the collection of sufficient samples necessary for a thorough evaluation of this process. First, a rainfall washoff comparison was only possible if a pre-event street surface sample had fortuitously been collected within 24 hours prior to an event. This eliminated most of the sites for most of the events. Secondly, following an event, field crew resources were spread thinly, collecting and processing samples from the eight stormwater monitoring stations and the eight atmospheric stations. Lastly, a post-event sample could only be collected after the streets had dried completely. While the crown of the streets generally dried quickly, puddles remained for longer periods. More so, cracks in the pavement and gutters remained damp for very long periods, sometimes days. In areas with streets in poor condition, these cracks held significant amounts of the total street load. When dry, the materials in these cracks were readily extracted by the vacuum samplers. When damp, extraction of these materials was seriously reduced. To obtain an unbiased comparison, the post-event sample could not be collected until the cracks were completely dry. Therefore, rainfall washoff comparisons could only be made if a site had been sampled just before a rain event, if event related stormwater and precipitation samples could be collected and processed expeditiously, and if post-event climatic conditions promoted rapid evaporation.

Nineteen rainfall washoff comparisons were made during this study (Table V.8). The washoff numbers in this table represent the net changes in street surface pollutant loadings following rainfall. Values for larger particles are positive, indicating a net increase in these particles following rainfall. This is not to say that none of the large particles were washed off of the street. Rather, that more of these particles were washed onto the street than were washed off of it. Similarly, while the net washoff values for smaller particles are very high (upwards of 80 percent) the actual washoff of the initial street loads were probably higher than this, but additional fine materials were undoubtedly washed onto the street in the same manner as the coarse materials. Probably sources of these washed in materials include washoff from the underbodies of passing cars, overhanging vegetation and adjacent landscaped areas. At Rustler, where there is no vegetation or adjacent pervious areas, there are many positive washoff numbers. On one hand, this indicates the significance of the washoff from the underside of cars. On the other hand, this also indicates the relative low washoff from flat surfaces (sheet flow) versus curb and gutter flow.

Washoff is extremely particle size dependent. As particle size decreases, washoff increases. This particle size removal function is very important as it relates to pollutant load distribution, street sweeper removal, and the subsequent water quality impact of street sweeping.

TABLE V.8

AVERAGE CHANGE* (%) OF STREET SURFACE CONTAMINANT LOADINGS FOLLOWING RAINFALL

Site	N	Average Rainfall (inches)	Particle Size (mm)											
			Min Max	4.0	2.0 4.0	1.0 2.0	.5 1.0	.25 .5	.125 .25	.063 .125	.031 .063	.031	Grass	Leaves	Total
State Fair	2	.41		-4.2	22.0	4.3	-12.3	-17.1	-20.3	-27.7	-24.5	-59.0	-93.0	-26.4	-7.5
Congress	7	.95		3.4	11.7	-7.1	-15.5	-32.7	-18.9	-27.5	-41.5	-60.4	21.5	-18.3	-16.4
Hastings	5	.47		-9.3	-3.5	-18.9	-38.1	-45.7	-45.5	-53.8	-61.6	-87.3	-70.7	52.2	-38.3
All Streets	14	.70		-2.0	15.4	-2.6	-18.0	-29.1	-25.9	-34.7	-42.2	-68.4	-15.3	-12.7	-17.3
Rustler Rough	2	.35		11.8	40.1	14.7	10.6	7.9	7.5	2.4	-25.2	-38.1	ID	ID	6.7
Rustler Smooth	3	.34		13.6	48.3	34.8	18.0	9.6	2.0	-20.0	-10.5	-12.2	ID	ID	3.3
All Parking Lots	5	.34		12.3	42.5	19.2	12.3	8.4	5.9	-6.1	-17.4	-20.8	ID	ID	5.7

* A negative value indicates a net decrease in street loads after rainfall, and a positive value indicates a net increase in street loads.

Only Congress and Hastings had sufficient washoff samples for comparative purposes. The average percent washoff was almost double at Hastings (Figure V.21), presumably attributable again to the difference in street texture and condition between Congress and Hastings. The difference in washoff largely compensates for the difference in street loads at these two sites. Street loads were roughly twice as high at Congress than at Hastings, but rainfall was only half as effective at washing material off the streets at Congress. Therefore, the amount of material being washed off both sites is relatively similar (Table V.9).

In an attempt to define predictive washoff relationships, multiple regression was employed with the data from Congress and Hastings. No statistically significant relationships were found for the data at Congress. At Hastings, a strong relationship was found between the square of the initial street load and the total amount washed off (total washoff=(initial load squared X .01575) - 1.821), r squared = .98. Addition of rainfall amounts and the square of the peak 30 minute rainfall intensities further increased r squared to .99. Washoff rates were correlated to rainfall amounts and peak intensities. The correlations were always positive but low. The strongest correlations (r=.35-.45) were found for medium and coarse sand (.25-1.0 mm). Correlations for all other sizes were less than .2.

Contribution of Street Washoff to Total Runoff

The maximum potential for street sweeping as an urban stormwater management practice is ultimately limited by the contribution of street surface contaminant runoff to total urban runoff, relative to other stormwater contaminant sources. Municipal street sweeping only affects loads on street surfaces, and obviously will have no impact on stormwater loads from roofs, lawns, privately owned parking lots, sidewalks, etc.. The greater the stormwater loadings from non-street sources, the less the water quality effect of street sweeping.

Two methods were used in this study to evaluate the contribution of street runoff to total urban runoff. The most direct method involved comparing street washoff values to concomitant event loads. Of the 19 washoff evaluations in this study, seven were at Congress where the water quality data was eventually discarded. Five were at Rustler Rough or Smooth, and all five washoff samples indicated a net gain in street load. Of the two washoff evaluations at State Fair, only one of the two concomitant events were sampled, and only two of the seven at Hastings. For these three events, 30, 67, and 61 percent of the total event loads appeared to come from washoff of street surfaces. Unfortunately, given the error in the street samples, there is not enough information here to begin to draw conclusions from.

Figure V.21

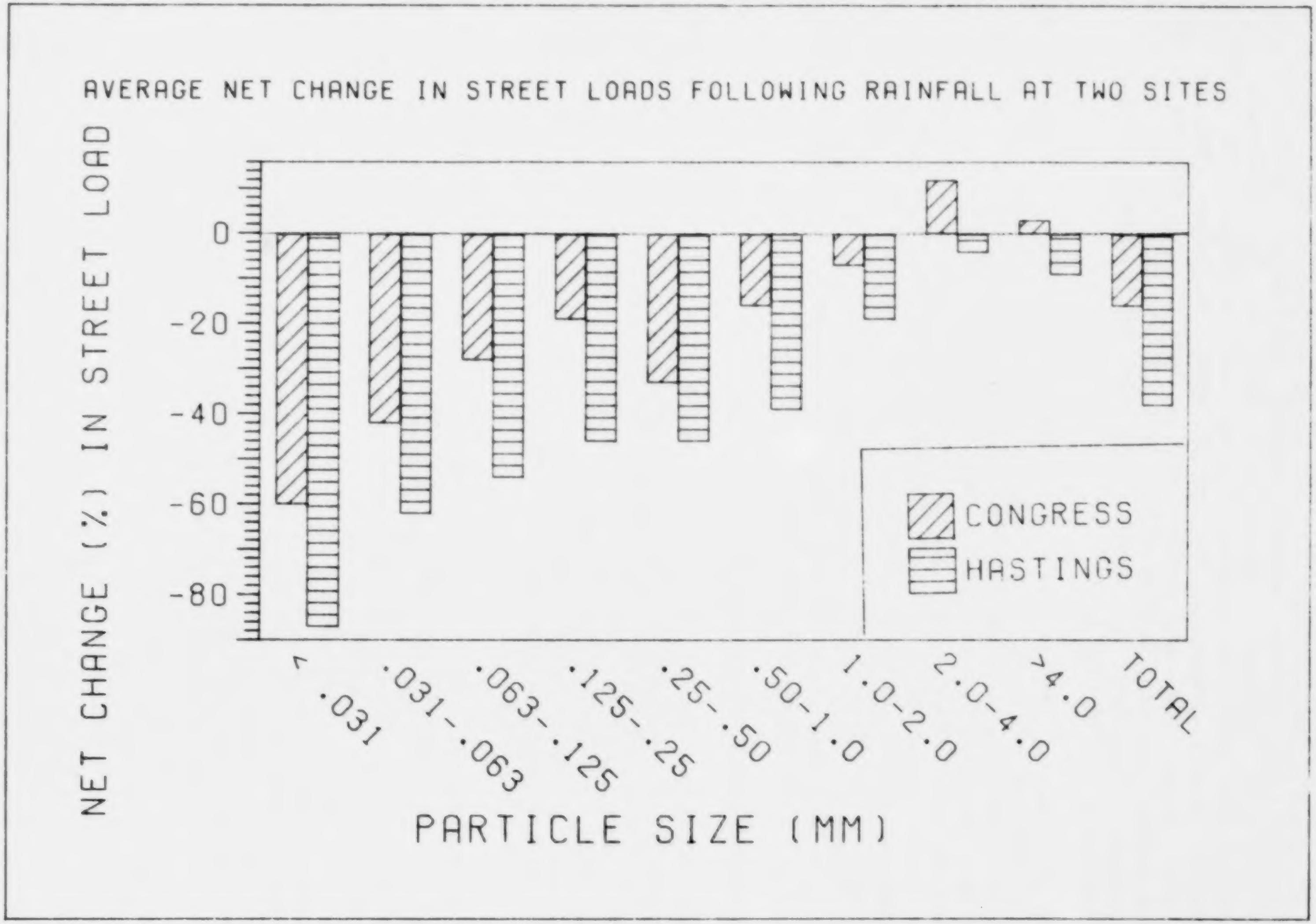

AVERAGE NET CHANGE IN STREET LOADS FOLLOWING RAINFALL AT TWO SITES
NET CHANGE (%) IN STREET LOAD
0
-20
-40
-60
-80
CONGRESS
HASTINGS
< .031
.031-.063
.063-.125
.125-.25
.25-.50
.50-1.0
1.0-2.0
2.0-4.0
>4.0
TOTAL
PARTICLE SIZE (MM)

TABLE V.9

RAINFALL-WASHOFF COMPARISON AT CONGRESS AND HASTINGS

Site		Particle Size (mm)											
	Min	4.0	2.0	1.0	.5	.25	.125	.063	.031				
	Max		4.0	2.0	1.0	.5	.25	.125	.063	.031	Grass	Leaves	Total
		Median Load on Street (g/curb m)											
Congress		3.34	2.06	2.31	2.31	3.60	2.57	1.80	1.29	1.29	1.03	4.11	25.7
Hastings		1.71	1.03	1.14	1.14	1.71	1.25	.91	.80	.69	.34	.57	11.4
		Average Rainfall Washoff (%)											
Congress		*	*	7	16	33	19	28	42	60	22	*	
Hastings		9	4	19	38	46	46	54	62	87	9	15	
		Average Load Removed by Rainfall (g/curb m) Computed From Above											
Congress		*	*	.16	.37	1.19	.49	.50	.54	.77	.23	*	4.25
Hastings		.15	.04	.22	.43	.79	.58	.49	.50	.60	.05	.07	3.92

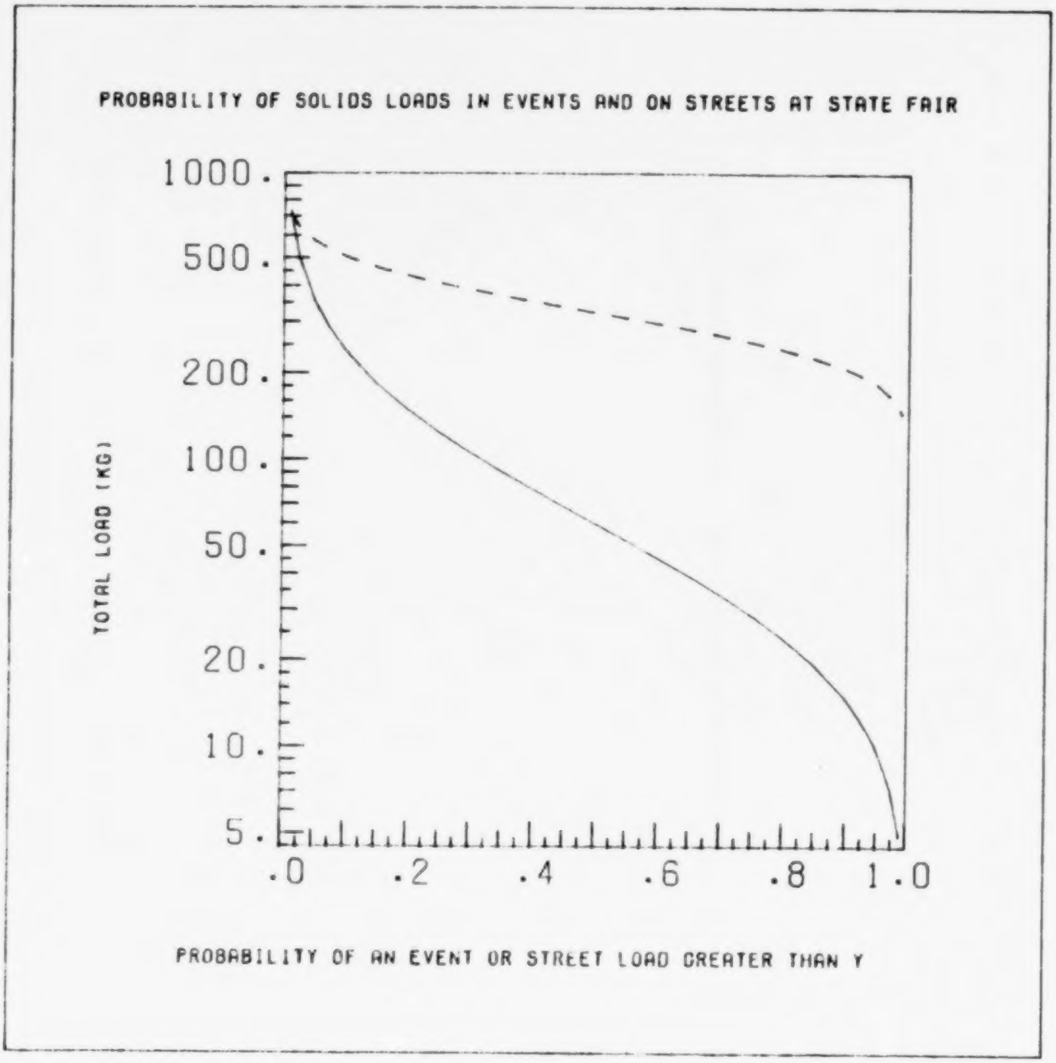
* Washoff comparisons indicated a net increase in street loads following rainfall.

A second less direct method involves comparing the distribution of street and stormwater event loads. Again, because of the problems with the water quality data at Congress, this analysis was only appropriate at State Fair and Hastings. Probability distributions for street loads and event loads for solids, volatile solids and phosphorus at State Fair between the months of May through September are presented in Figures V.22-24. Data regarding distribution of these parameters plus lead and C.O.D. at Hastings as well as State Fair is presented in Table V.10. Care must be exercised in properly interpreting this data however. This data indicates probability distributions only. Event loads are neither independent of nor entirely dependent on street loads. Street loads are one of a number of significant determinants of event loads. Other variables believed to affect event loads are rainfall amounts and intensities, traffic patterns, antecedent soil moisture conditions and contaminant deposition and scour in storm sewers, etc.. Therefore, one can not assume that the largest event loads coincide with the largest street loads or vice-versa.

For each parameter at both State Fair as well as Hastings, the range of street loads is much smaller than, and contained within, the range of event loads. The primary difference among the various parameters is the location of the range of street loads within the range of event loads. If the range of street loads is high within the range of event loads, such as for lead and solids, than street loads probably contribute the majority of these contaminants to the majority of event loads. Streets do not appear to be source limiting for these parameters for most events, i.e., for most events, streets have the potential to supply all or most of the lead and solids. If however, the range of street loads is low within the range of event loads, such as for phosphorus and C.O.D., than other non-street contaminant sources must be contributing extensively to the majority of event loads. Street loads are source limiting for these parameters. At State Fair and Hastings, 41 and 57 percent respectively of the event loads of phosphorus are larger than the largest 1 percent of the street loads. For moderate to large events, there are other major sources of phosphorus in these watersheds. For very small events though, the street loads have the potential to supply all of the phosphorus.

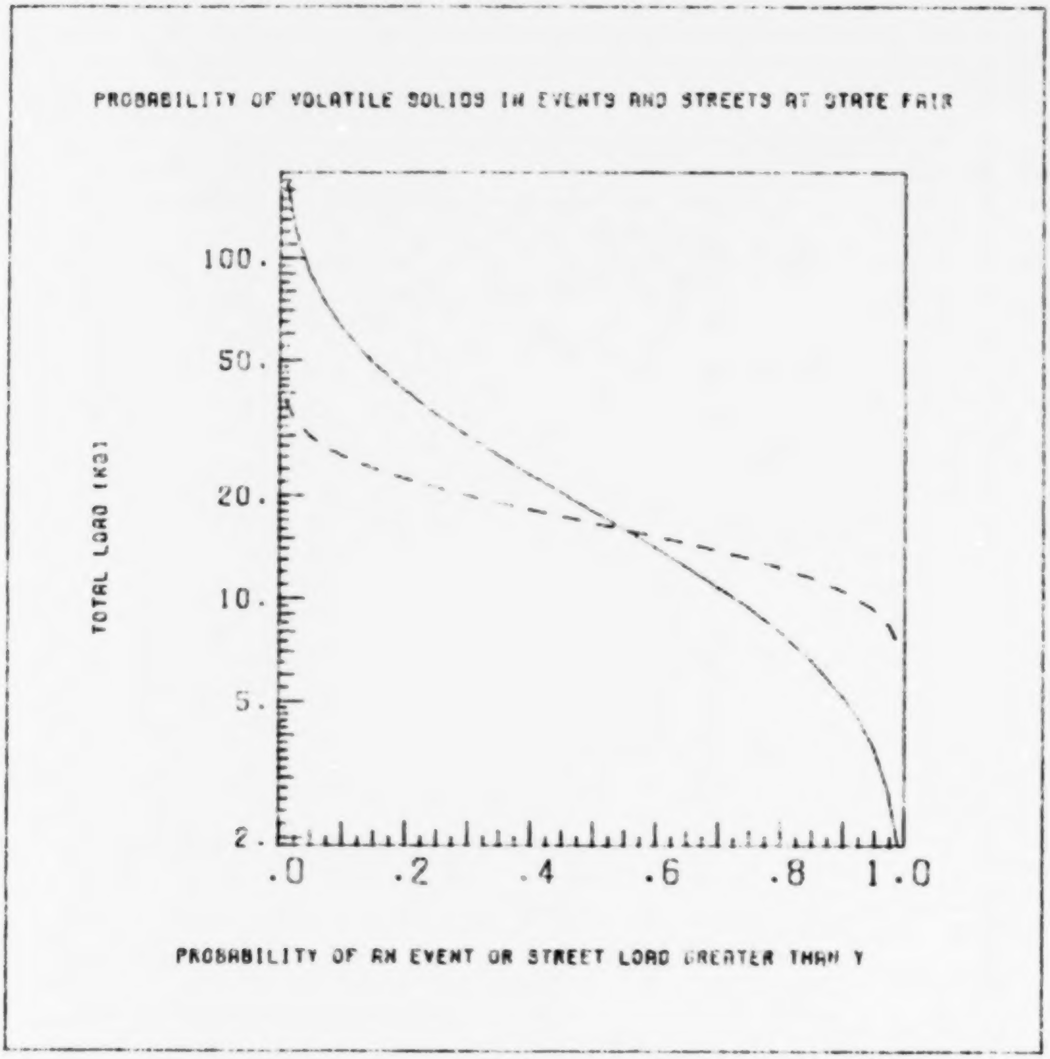
Based on these probability distributions, the relative ranking of the contribution of street surface contaminants to stormwater loads are (in greatest to least order) lead, solids, volatile solids, phosphorus and C.O.D. at State Fair, and solids, lead, volatile solids, C.O.D. and phosphorus at Hastings. It follows then that the relative water quality effects of street sweeping also proceed in similar fashion.

FIGURE V.22



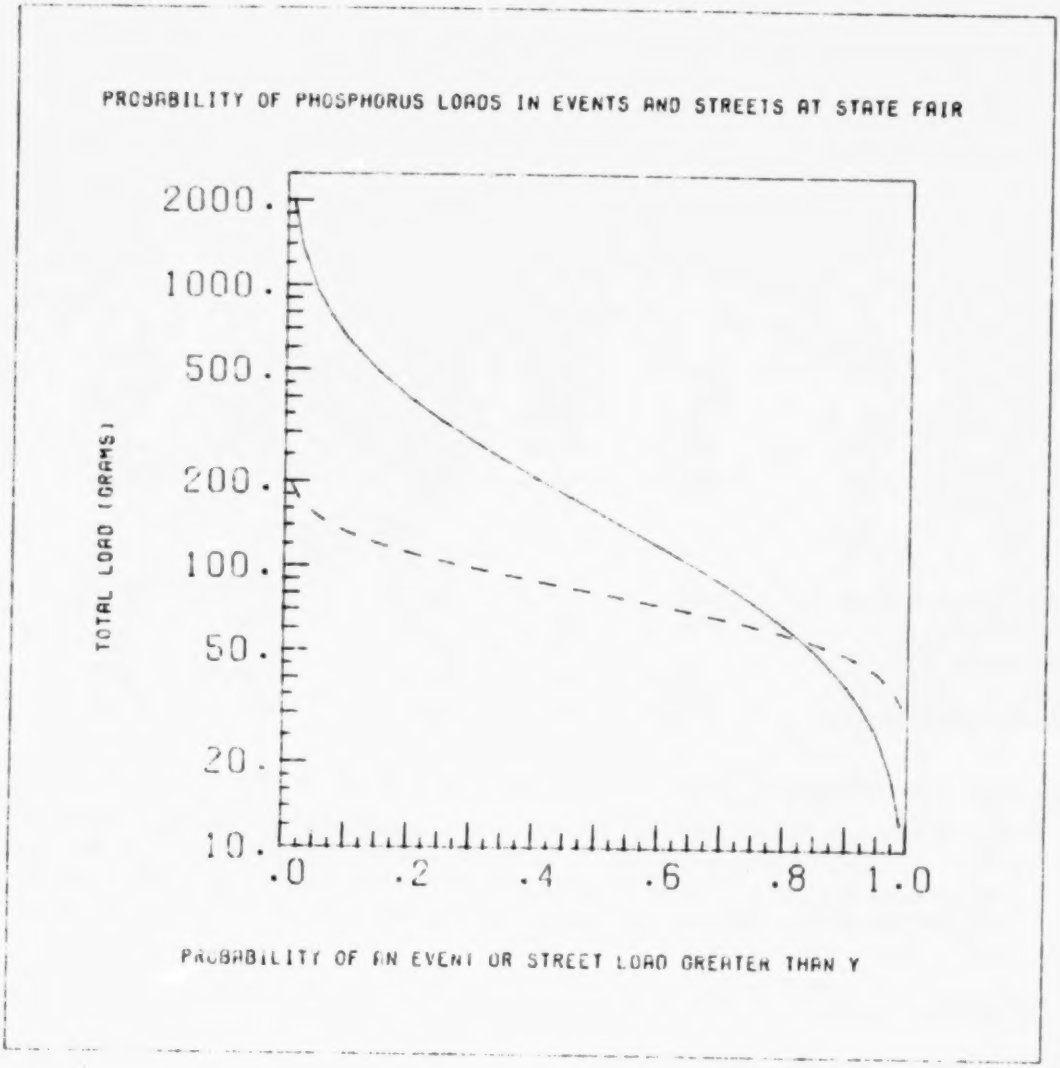
Solid line is event load probability (kg/event)
Broken line is street load probability (kg/total street surface), May - September.

FIGURE V.23



Solid line is event load probability (kg/event)
Boken line is street load probability (kg/total street surface),
May - September.

FIGURE V.24



Solid line is event load probability (g/event).
Broken line is street load probability (g/total street surface), May - September.

TABLE V.10

EVENT AND STREET LOADS* FOR THREE PROBABILITIES AT STATE FAIR AND HASTINGS, MAY-SEPTEMBER

	Event Loads**			Street Loads***		
	.05	.50	.95	.05	.50	.95
				State Fair		
Suspended Solids	352.7	59.9	10.2	572.4	323.8	183.1
Total Lead	805.9	156.0	30.2	1,444.6	692.3	331.8
Volatile Solids	88.7	18.0	3.7	29.8	16.6	9.3
COD	238.3	49.0	10.1	43.0	23.3	12.7
Total Phosphorus	959.3	157.6	25.9	152.5	80.6	42.6
				Hastings		
Suspended Solids	105.9	14.8	2.1	90.1	40.0	17.8
Total Lead	233.9	34.8	5.2	143.4	55.7	21.6
Volatile Solids	31.8	5.2	0.9	11.5	3.9	1.3
COD	94.4	14.8	2.3	14.6	5.0	1.7
Total Phosphorus	532.9	80.6	12.2	44.1	17.1	6.6

---

* Loads are estimates of minimal values for given probability levels (P=.05, .50, .95). For example, there is a .05 probability that an event load of suspended solids at State Fair would be greater than 352.7 Kg. Units are Kg for suspended solids, volatile solids and COD, and grams for total lead and total phosphorus.

** Event loads are total loads per event

*** Street loads are total loads on the streets of a watershed at any point in time.

ATMOSPHERIC CONTAMINANT DEPOSITION

The primary sources of atmospheric pollutants are natural and cultural in origin, including such components as volcanic and vegetative emissions, soil erosion by wind, combustion, and industrial and vehicular emissions (Stern, 1976). Atmospheric monitoring at the earth surface involves sampling a mixture of contaminants from global, regional and local sources, the relative importance of which varies with location, time and contaminant. Walling (1980) makes the point that the chemical quality of atmospheric inputs to a basin will vary in both time and space in response to a number of factors, including atmospheric controls such as air mass movement and wind and storm direction. Atmospheric input to the earth occurs though processes of wet deposition, or precipitation events, and dry deposition. Atmospheric pollutants are a source of contamination to receiving waters through direct input to lakes and streams, and to drainage basin surfaces. The latter becomes increasingly important with urbanization because of the greater stormwater runoff from impervious surfaces. The significance of atmospheric contaminant contributions to stormwater has been addressed by a number of investigators.

Betson (1978) found atmospheric wet and dry deposition to be an important contributor to stormwater contamination in urban watersheds. Huff (1976) found atmospheric inputs small with respect to annual stream pollutant loads from a rural watershed, with the exception of nitrogen and zinc, thought to originate from industrial stacks upwind of the site. Barkdoll et al. (1977) estimated that there can be contributions to the urban stormwater loading of COD, mercury, chloride and phosphorus from dry weather atmospheric deposition. Variability of dry weather atmospheric deposition of some contaminants with land use has been identified, with deposition rates generally increasing from rural to residential to commercial and industrial land uses (Andren, et al., 1979; Goettle, 1978; Rossano, et al., 1966). Solomon et al. (1977) subdivide land use related sources into three components; local sources such as vehicular traffic in a street adjacent to he sampler; more diffuse sources, such as all the street traffic in a city; and background, which is regional or global in scope.

Atmospheric dry deposition particulates have a high surface area to weight ratio. These small diameter particles are easily transported by water, difficult to remove in sediment traps, inefficiently removed by existing street cleaning practices, and easily resuspended and redistributed by light winds, such as generated by traffic (Pope, 1980). Galloway (1978) identified dry fallout, aerosols and adsorbed gases as three subcomponents of dry weather atmospheric deposition. Dry fallout consists of particles larger than 2 microns in diameter which are significantly affected by gravity. Aerosols are smaller particles, deposited on earth surfaces by impaction. Adsorbed gases are gaseous contaminants adsorbed on particles or earth surfaces.

Precipitation quality considerations include acidity, toxic metals, organic chemicals, phosphorus and nitrogen compounds in quantities harmful to cultural and natural systems. Contaminants are incorporated into precipitation within and below clouds through a process of scavenging. Atmospheric particles and gases that collide with moving water drops are adsorbed by the water. Scavenging within clouds is termed rainout or snowout, below-cloud enrichment is known as washout (Stern, 1976). Characklis et al. (1979) found higher ammonia concentrations in rainwater and streamwater at a highly developed site than at a forested site, although Andren et al. (1979) found no spatial or seasonal variation in lead concentration in rainwater. There may be an inverse relationship between rain contaminant concentration and rain event volume for some pollutants (Huff, 1976). In a summary of urban runoff research, Pope (1980) indicates contaminants in precipitation are often significant inputs to stormwater loads and may exceed stormwater concentrations.

Atmospheric Deposition Monitoring

Atmospheric monitoring of wet and dry deposition was conducted at eight sites adjacent to the NURP drainage basins. The monitoring program was initiated in the spring of 1981, and continued through June of 1982.

A total of 242 wet deposition samples were obtained from 45 different events. Three of the events were snowfall, including an event from December, 1980, sampled before the complete monitoring network was in place. Samples were not obtained at every site for every event because of equipment malfunction or sample contamination and subsequent rejection. The event-to-event variation in precipitation volume resulted in varying sample amounts collected. For many smaller events, insufficient sample was collected to analyze all pollutants on the parameter list. A 3-level priority sequence was developed to aid in analysis. Parameters in the first priority included total solids, total and soluble phosphorus, and total lead. The second priority included sulfate, soluble lead, acidity, ammonia and nitrate plus nitrite. The third priority included chloride, suspended solids, chemical oxygen demand, ph and conductivity.

The exposure period for atmospheric dry deposition varied among sites throughout the monitoring program. The median exposure period was 14 days, with arithmetic mean of 17.5 and range from 10 to 79 days. A total of 112 total lead and total phosphorus samples were obtained. Insufficient volume for analysis or lab error reduced the number of samples for total solids, COD and sulfate to slightly less than 112.

All samples were collected with N-CON wet/dry deposition collectors. Collectors at the Southeast District Headquarters and Oil Gear Corporation sites were located on platforms two meters above the ground. The remaining six collectors were located on flat roofs ranging in height from 5.8 to 17.4 meters, with a mean height of 10.6 m. Monitoring methods, sampler locations and adjacent land uses are more fully described in Volume III, Chapter III.

ATMOSPHERIC DRY DEPOSITION

Previous investigators have often used samplers located near the ground for the collection of bulk and dry atmospheric deposition. Recognizing the mixture of local, regional and global sources of atmospheric contaminants, low height samplers may be disproportionally influenced by local sources through sampling of particulates suspended by local air turbulence, including larger particulates. Barkdoll, et al. (1977) discuss the problem of resampling resuspended material with a ground level collector. Conversely, turbulence and eddys may scour the collector, removing material previously sampled. In addition, air circulation around structures can be extremely complex, resulting in variable deposition patterns near ground level.

Given these considerations, an attempt was made to locate the majority of collectors on roofs of tall buildings, high enough to reduce the effects of local air turbulence. Therefore, the collected samples are not representative of the flux of airborne material at the street surface. Hicks et al. (1980) urge caution in the extension of deposition estimates from bucket collectors to atmospheric deposition to other surfaces, indicating that the complex physical interactions between natural surfaces, fine aerosols and gaseous components are poorly understood.

Characterization of Dry Deposition

The solids collected in the dry deposition buckets were analyzed for chemical constituents. Table V.11 presents the composition of the total solids by percent weight of phosphorus, lead, COD and sulfate. Phosphorus and lead average approximately one tenth of one percent of total solids collected. The percentage of phosphorus found in small particle sizes of surface mineral soils in the Milwaukee region is in the same range as that found in dry deposition, averaging .03% and .23% for silt and clay, respectively. However, the percentage of lead is orders of magnitude higher in dry deposition than in regional soils, averaging .001 for silt and .005 for clay (Dong, 1979). A major source of phosphorus therefore, is probably urban and agricultural soil subject to wind erosion, while lead inputs are not related to regional geography. The major source of atmospheric lead is combustion of gasoline with lead anti-knock compounds in automobiles (Stern, 1976; Novotny et al. 1981). Primary COD sources are poorly documented, but probably include vegetation, soil organization and combustion emissions. Primary atmospheric sulfur sources include oil and coal burning for power generation, as well as biological and volcanic activity (Stern, 1976).

Contaminant percentages by weight of total solids are similar in spring and summer. In November and December, percentages are higher for lead and sulfate and lower for phosphorus and COD. Walling (1980) indicates that thermal stratification in the atmosphere during cold weather may result in increasing accumulation of contaminants in lower atmospheric layers, although a blanket of snow may reduce the availability of terrestial contaminants. Given relatively constant emissions of lead, and perhaps sulfate, thermal stratification could increase their concentration in total solids deposition. Frozen and snow-covered soils are not susceptible to wind erosion and transport, reducing the availability of these phosphorus sources during winter months.

TABLE V.11

COMPOSITION OF TOTAL SOLIDS IN DRY DEPOSITION

	Arithmetic Mean Percent by Weight			
	Total Phosphorus	Total Lead	COD	Sulfate
All samples*	0.11 + .06	0.13 + .06	40.6 + 17.5	5.3 + 3.2
Ranges	0.02 - 0.33	0.01 - 0.39	7.1 - 96.7	0.3 - 16.7
January - May	0.10 (41)	0.11 (40)	40.9 (28)	4.8 (35)
June - October	0.11 (42)	0.12 (42)	44.4 (36)	5.3 (38)
November - December	0.08 (10)	0.15 (10)	35.3 (10)	6.8 (10)

* Arithmetic mean ± standard deviation.
() Number of samples.

Dry Deposition Rate Computation

The mass of contaminants collected in each deposition sample was normalized to a deposition rate of mg/square meter/day by correcting for the area of the collector opening and the number of hours the collector was operating in the dry mode. The distributions of dry deposition rates were best described by log-normal distributions. All subsequent analyses were conducted on the natural logarithm of the computed rates.

Deposition Rates Under Strong Wind Conditions

Although the deposition rate is necessarily an average over the entire collection period, it was suspected that short-term episodic weather conditions might play an important role in the collection of contaminants. To assess the influence of winds on dry deposition, the deposition rates were stratified according to presence or absence of strong winds during the collection period. Strong winds were arbitrarily defined as greater than 20 miles per hour. This analysis might be improved by considering a range of wind speeds and duration, with site specific wind data. Given the general nature of the existing data, this increased level of detail was not considered justified. The deposition rates of total solids, total lead and sulfate during collection periods with high winds were not significantly different from periods without high winds. The deposition rates of total phosphorus and COD for collection periods with high winds were different at .05 significance level from those for periods without high winds, higher by approximately 60% and 30% respectively.

Seasonal Variation in Deposition Rates

Table V.12 presents mean seasonal dry deposition rates and ranges. Deposition rates for total solids and COD are significantly higher in the spring, while phosphorus deposition is significantly lower in the winter. Exposed soil, which is a major source of these contaminants, varies in extent with seasonal agricultural practices. Sulfate and lead exhibit no significant seasonal variation, indicating relatively constant sources.

Variation in Deposition Rates Among Sites

Although the "airshed" or contaminant contributing area undoubtedly varies for each contaminant not only with time but also spatially along horizontal and vertical gradients, some distinct trends can be seen through site-by-site deposition rate comparisons. Analysis of variance indicated no spatial trends for the contaminants phosphorus and sulfate. All the sites monitored the same air quality for these pollutants. However, significant spatial trends in deposition rates are indicated for the contaminants total solids, lead and COD. Table V.13 presents geometric mean deposition rates by monitoring sites, arranged in order of generally increasing mean rates.

The Southeast District Headquarters, Oil Gear and St. Bernadette sites all have in common open grassy space adjacent to the sampler. However, samplers

TABLE V.12

SEASONAL MEAN CONTAMINANT DRY DEPOSITION RATES

	Geometic Mean Deposition Rate (mg/m^2/day)				
	Total Solids	Total Phosphorus	Total Lead	COD	Sulfate
All samples*	50. + 2.	.048 + .002	.052 + .003	17.4 + 1.9	2.1 + 1.9
Ranges	11. - 735.	.007 - .421	.001 - .390	1.2 - 86.7	.52 - 8.67
Jan. - May	76. A	.062 A	.054 A	23.7 A	2.5 A
	(28)	(36)	(36)	(29)	(29)
June - Oct.	45. B	.050 A	.053 A	16.5 B	2.0 A
	(53)	(62)	(62)	(50)	(52)
Nov. - Dec.	32. B	.021 B	.042 A	10.9 C	2.0 A
	(12)	(14)	(14)	(14)	(14)

* Geometric mean + standard deviation.
() Number of samples.

Seasonal means for a given contaminant followed by the same letter are not different at .05 significance level, as indicated by Duncan's multiple range test.

TABLE V.13

GEOMETRIC MEAN DRY DEPOSITION RATES AT MONITORING SITES

Station	Deposition Rate at Ground Sites ($mg/m^2/day$) Total Solids	Total Lead	COD
Southeast District H.Q.	33.2	.047	14.2
Oil Gear Corporation	31.7	.039	11.0

Station	Deposition Rate at Elevated Sites ($mg/m^2/day$) Total Solids	Total Lead	COD
St. Bernadette School	43.4	.026	12.9
Dept. of Public Works	55.5	.057	16.1
Wis. Telephone Co.	48.8	.063	17.6
Wood Veterans Hospital	54.0	.055	21.8
Appleton Avenue	59.3	.080	22.8
West Allis City Hall	76.8	.070	24.6

at the Southeast District Headquarters and Oil Gear Corporation are located on ground platforms, at approximately two meters elevation. Data from these sites should be compared with data from elevated samplers with caution.

Examination of the atmospheric site descriptions in Volume III reveals that the increasing deposition rates for solids, lead and COD are associated with increasing intensity of land uses. Adjacent land uses for the elevated sites are ordered from medium to high density residential, to commercial, and from low traffic to high traffic. Increasing deposition rates indicate that some portion of the solids, lead and COD sources are related to local land uses.

ATMOSPHERIC WET DEPOSITION

The 45 monitored precipitation events have a geometric mean of .39 inches of water equivalent, and range in size from .05 to 4.71 inches. Concentration data is generally log-normally distributed. With the exception of pH and acidity, analyses were performed on natural log transformations of the concentration values.

Variation in Concentrations Between Sites

Analysis of variance, Duncan's multiple range test and t-tests revealed no differences in concentration data among the monitoring sites for all contaminants at a .05 significance level. There were no significant differences in the wet deposition quality at the monitoring sites. This suggests less influence of local sources and land uses on wet deposition than on dry deposition. Ter Har et al. (1967) point out that rainwater falls through a long column of air beginning at high altitudes, and therefore samples a large air volume, minimizing the effect of local air quality on precipitation quality.

Comparison of Rainfall and Snowfall Quality

Walling (1980) indicates that higher snowfall concentrations of some contaminants may be attributed to the greater relative surface area of snowflakes, providing increased capacity of snowflakes to trap aerosols, as well as the atmospheric thermal stratification in urban areas which may increase accumulation of aerosols. Total lead concentrations in the three monitored snowfall events, with a geometric mean of .029 mg/l, are higher than the rainfall lead concentrations at a significance level of .01. Mean snowfall concentrations of COD, sulfate, ammonia and nitrate plus nitrite are higher than mean rainfall concentrations, but are not statistically different. The low statistical significance is strongly influenced by the small number of samples obtained during snowfall events.

Seasonal Variation in Precipitation Concentrations

Analysis of variance revealed significant monthly differences in concentration distributions for some contaminants. Concentration data were aggregated into three seasons based upon the similarity of monthly distributions. Tables V.14-15 presents contaminant geometric means and ranges for all event samples and for seasonally stratified events.

TABLE V.14

SEASONAL WET DEPOSITION CONTAMINANT CONCENTRATIONS

	Geometric Mean Event Concentration (mg/l)						
	Total Solids	Suspended Solids	Total Phosphorus	Total Lead	COD	Sulfate	pH*
All Samples	10. + 4.	4. + 3	.015 + .002	.012 + .002	7. + 1.8	4.2 + 1.7	4.2 + .5
Range	< 2. - 100.	< 2. - 53.	< .004 - .140	< .003 - .110	2.5 - 34.0	1.6 - 12.0	3.0 - 6.0
Jan. - May	19. A (30)	8. A (22)	.024 A (41)	.013 A (37)	8.2 AB (16)	4.5 A (33)	4.6 A (31)
June - Oct.	10. B (124)	3. B (63)	.013 B (134)	.010 B (153)	6.5 A (77)	4.1 A (113)	4.0 B (91)
Nov. - Dec.	7. B (25)	13. A (4)	.014 B (22)	.025 C (25)	13.6 B (6)	4.1 A (17)	4.3 AB (12)

() Number of samples.
* Arithmetic mean for pH.

Seasonal means for a given contaminant followed by the same letter are not different at .05 significance level, as indicated by Duncan's multiple range test.

TABLE V.15

SEASONAL WET DEPOSITION CONTAMINANT CONCENTRATIONS

	Geometric Mean Event Concentration (mg/l)						
	Soluble Phosphorus	Soluble Lead	Total Kjeldahl-N	Total Ammonia-N	Total Nitrate plus Nitrite	Conductivity**	Acidity*
All Samples Range	.006 ± .002 <.004 - .059	.006 ± .002 <.003 - .036	.36 ± .002 <.20 - 1.00	.49 ± .002 .07 - 2.10	.54 ± .30 <.02 - 1.70	.31 ± 2. 10. - 102.	8.1 ± 4.7 1.9 - 22.1
Jan. - May	.009 A (37)	.004 A (29)	.24 A (5)	.48 A (33)	.50 A (33)	28. A (29)	4.5 A (21)
June - Oct.	.005 (82)	.006 B (94)	.64 B (7)	.47 A (121)	.49 A (125)	32. A (92)	9.2 B (72)
Nov. - Dec.	.008 A (14)	.011 C (8)	.20 A (2)	.73 B (15)	1.03 B (15)	31. A (7)	7.0 AB (7)

() Number of Samples
*Arithmetic mean for acidity, units are mg/l $CaCO_3$.
**Conductivity units are umohs/l.

Seasonal means for a given contaminant followed by the same letter are not different at .05 significance level, as indicated by Duncan's multiple range test.

Conductivity and sulfate show no variability in concentration with seasons. The pH and acidity values both indicate that precipitation is most acidic in the summer, and least acidic in the spring.

Higher concentrations of total solids and total phosphorus are found in spring precipitation. Highest concentrations of total lead, COD, total ammonia and nitrate plus nitrite are sampled during winter events.

Comparison of Dry Deposition and Wet Deposition

For some contaminants, similar trends are seen in both wet and dry deposition. Although the concentration of sulfate in dry deposition solids is higher in the winter, the dry deposition rate and precipitation concentrations are relatively uniform, exhibiting no significant seasonal variation. Concentrations of lead in precipitation and dry deposition solids are higher during winter, possibly related to cold weather atmospheric stratification and snowfall scavenging effectiveness. The lower dry deposition rate of phosphorus in winter months, the increased deposition of total solids in spring, and the higher concentrations of solids and phosphorus in spring precipitation are most probably related to the seasonal variation in continental land surface exposed to wind erosion.

Trace Metals in Rainwater

Thirty-eight rainwater samples from eight events during the summer of 1981 were analyzed for trace metals. The results of the multi-element scan analysis is presented in Table V.16. For many metals, all of the samples were below their respective concentration detection limits. Soils of the region are rich in calcium and magnesium, and both elements were generally above detection limit in the rainwater samples. The zinc concentration during one event exceeded the detection limit, with a mean of 2.0 mg/l.

Comparison of Concentration Data with Other Monitoring Programs.

The range of event sulfate concentrations are somewhat higher than the mean monthly concentrations sampled in 1982 at six sites across Wisconsin, which range from .67 to 5.74 mg/l (Sheffy et al. 1983). Comparison of pH values in the same report indicates that precipitation may be slightly less acidic throughout the state than at the NURP sites.

Andren et al. (1979) estimated an average total phosphorus concentration of .015 mg/l in rainwater in the Milwaukee area, equal to the geometric mean concentration monitored in this study. They also estimated an approximate lead concentration in rainwater of .030 mg/l, and found no seasonal or spatial trends. While the range of lead concentrations sampled in this study is similar to theirs, less than .003 to .110 mg/l compared with .010 to .130 mg/l respectively, the mean of .012 is significantly less than their figure. Although no spatial trends were found, substantial seasonal differences in lead concentration were identified in this study.

TABLE V.16

MULTI-ELEMENT SCAN ANALYSIS OF METALS IN RAINWATER

Metals Generally Below Concentration Detection Limit (mg/l)

Cd	<.005	Cr	<.010
Co	<.005	Cu	<.010
Be	<.001	Mo	<.010
As	<.050	Ni	<.010
Ag	<.020	Sn	<.010
Mn	<.020	V	<.010
Sb	<.020	Zn	<.010*
Se	<.020	Fe	<.100**

Geometric Mean Concentration of Metals Above Detection Limit (mg/l)

	N	Mean Concentration	Range
Ca	35	.9	<.05 - 23.0
Mg	29	.2	<.05 - 0.8

* Zn concentrations averaged 2.0 mg/l for one rain event.
** Fe concentrations reached 0.2 mg/l in three samples.

Contaminant Concentrations, Precipitation Volume and Preceeding Dry Interval

Analysis of variance, linear correlation and stepwise multiple regression were used to relate all precipitation contaminant concentrations and the geometric mean of concentration data for each event to the event water equivalent volume and to the dry weather time interval proceeding the event as well as the log transform of these variables. In general, the independent variables precipitation volume and dry weather interval showed poor correlation with contaminant concentrations. Seasonal stratification did not improve the predictive ability of either independent variable. Although contaminant concentrations generally varied widely for a given range of precipitation volume or preceding dry interval, and correlation coefficients and regression r^2 values were low, concentrations were generally positively related to proceeding dry interval and negatively related to precipitation volume. Therefore, although variable, contaminants show a trend of increasing concentration with increasing dry interval length, and decreasing concentration with increasing precipitation volume.

Precipitation Contaminant Contribution to Runoff Quality

To better assess the significance of precipitation quality to stormwater quality, rain concentrations were compared to drainage basin runoff concentrations for those events when both were monitored. Stormwater was not monitored for any snow events. The ratio of rain concentration to stormwater concentration was computed on an event basis for each contaminant that was sampled. The percent contribution of rain quality to stormwater concentrations was not clearly related to event rainfall volume for any contaminants.

Seasonal comparison of the percent rain contribution to stormwater concentration indicates that the spring and summer ratios are not significantly different for all contaminants except COD. Rain contributed an average of 10% of the runoff COD in spring and an average of 20% in summer.

Table V.17 presents the mean percent rain contaminant contribution to stormwater contaminant concentration for drainage basins. In general, for solids, phosphorus, lead and COD, the stormwater proportion attributed to rain decreases with increasing intensity of land use and the presence of additional contaminant sources.

The total ammonia concentration in rainfall generally exceeds the concentration in stormwater. The average ratio of total nitrite plus nitrate in rainwater to stormwater ranges from 50 to 100%. Precipitation has long been recognized as a source of nitrogen to land and surface waters. However, nitrogen chemistry is complex. The different forms of nitrogen are capable of transformation through a number of processes. Further research is required to fully characterize the nitrogen cycle in the Milwaukee urban area.

TABLE V.17

EVENT COMPARISON OF RAIN CONTAMINANT CONCENTRATIONS AND RUNOFF CONCENTRATIONS

Average Ratio (%) of Rain to Drainage Basin Stormwater Concentration

	Total Solids	Suspended Solids	Total Phosphorus	Total Ammonia	Nitrate & Nitrite	Total Lead	COD
State Fair	9.8	9.2	7.9	108.9	49.3	6.7	11.8
Wood Center	8.5	3.4	6.6	136.5	76.0	3.3	11.9
Lincoln	11.4	11.7	5.8	159.3	52.1	10.0	9.7
Hastings	23.4	15.6	9.3	261.0	100.3	18.3	17.7
Rustler	13.4	16.3	16.1	100.7	49.6	13.4	19.5
Post Office	18.3	13.9	17.1	129.6	86.2	13.8	17.5

ROOFTOP RUNOFF QUALITY

Although roof surfaces have long been recognized as contributors to stormwater volume in urban hydrology, little mention has been made of their contributions to stormwater quality. Rooftop runoff contaminants are a mixture of precipitation pollutants, materials accumulated on roofs during anteceedent dry weather, atmospheric deposition, vegetative deposits and wind transported contaminants, as well as materials made available through physical and chemical weathering of roof and water collection system surfaces.

In established Milwaukee residential areas, rooftops are generally sloping, with a roof water collection system of eaves troughs and downspouts. Roofs in commercial districts are generally a mixture of sloping and flat, with some form of drain or downspout conveyance system. Downspouts may lead directly to the subsurface stormsewer system, especially in commercial areas, or they may deliver to impervious surfaces such as streets, sidewalks and driveways, some of which are hydrologically connected to the stormwater system, or finally, they may drain to pervious areas such as lawns, which may become hydrologically connected to the stormsewer system under certain conditions.

Rooftop Runoff Monitoring

Runoff from three sloping residential roofs was monitored on an event basis, using a sampler located in the eaves troughs. Monitoring took place in November of 1981, and in March through June of 1982. A total of 48 samples were collected from 19 separate events. Samples were not obtained at each roof monitoring site for each event because of lab error, contamination, or inability to process the sample in a timely fashion.

Individual samples were obtained by collecting all the water that fell on a portion of the roof for the duration of the event, providing mean event contaminant concentrations. Sites Sylvester and Ewald are roofs of 45 degree slope with southern and eastern aspect, respectively. Site Virgil is a roof of 20 degree slope with a northern aspect. The sampled roofs are representative in design and construction materials used of residential roofs found throughout the drainage basins. A more detailed explanation is presented in Volume III, Chapter III of this report.

Grab samples were taken in the downspouts of 2 commercial buildings with flat roofs during events. Grab sample values are only indicative of concentrations present at some time during a rooftop runoff event. Flat roof sampling is further complicated by the greater residence time of water on the roof compared to sloping roofs, which may allow some larger particles to settle out.

It should be recognized that the sampled rooftop area represents only a small portion of the total roof surface in the drainage basins, and that the monitoring program does not address the variability in contaminants from roof to roof. Investigating the importance of such factors as elevation, slope, aspect, local turbulence and roofing materials to rooftop contaminants is beyond the scope of this study.

Variation in Rooftop Runoff Contaminant Concentrations Among Sites

Tables V.18-19 present geometric means of residential rooftop mean event runoff contaminant concentrations, as well as grab sample concentrations from flat commercial roofs. The grab samples generally fall within the range of the event mean concentrations from the residential roofs.

The small number of events sampled preclude any significant seasonal analysis. However, some effect of local land uses may be seen, although all three samplers were located on residential structures. The Sylvester site, adjacent to the mixed land use State Fair drainage basin, has higher event mean concentrations for many pollutants than the other samplers which are located in areas of medium and high density residential land uses. Given the spatial homogeniety of wet precipitation, this variability is probably related to differences in dry atmospheric deposition and local wind deposition and removal. In general, rooftop runoff solids, phosphorus and lead concentrations decrease from commercial to residential sites, and lead and phosphorus concentrations decrease further from high density residential to medium density residential sites.

Comparison of Rooftop and Atmospheric Deposition

Rooftop Runoff Contaminants and Dry Deposition--

The dry deposition of total solids, total lead and COD varies with land uses, as shown in Table V.13. The increase in dry deposition rate from residential to commercial sites, and from areas of low vehicular traffic to higher traffic volume supports the trend in rooftop runoff concentrations for these contaminants. Spatial analysis of atmospheric dry deposition of phosphorus and sulfate does not support a trend of variation with land use. The variation seen in rooftop runoff for these contaminants may indicate the presence of other sources, as well as the impact of local wind deposition and removal.

Rooftop Runoff Contaminants and Anteceedent Dry Period--

Net rooftop runoff concentrations were computed by subtracting the event rain concentrations from the rooftop concentrations. The net concentration data and event rain volume were used to compute an estimated contaminant load. This contaminant load contributed solely by the roof was compared to the time since the previous rain event, or anteceedent dry period. These data for solids, phosphorus and lead show a trend of positive correlation, but generally have low ($r \leqslant .4$) correlation coefficients. The mass of these contaminants available for washoff from roof surfaces generally increases with accumulation time, but the scatter in the data precludes computation of accumulation rates. No trend of increasing contaminant mass with anteceedent dry period was seen for total zinc, sulfate, total ammonia-N or nitrate plus nitrite-N.

Comparison of Rainfall and Rooftop Runoff Contaminants--

To assess the contribution of rainfall contaminants to rooftop runoff quality, concentration data were compared for simultaneously monitored events. Table V.20 presents the mean ratio of rainfall concentrations to rooftop

TABLE V.18

ROOFTOP RUNOFF CONTAMINANT CONCENTRATIONS

	Total Solids	Suspended Solids	Total Phosphorus	Total Lead	Sulfate	COD	Total Zinc
Geometric Mean Event Concentration From Sloping Residential Roofs (mg/l)							
Sylvester	85. (18)	36. (17)	.065 (18)	.070 (18)	12.2 (16)	38.7 (11)	.642 (18)
Ewald	52. (10)	16. (9)	.056 (13)	.040 (13)	6.7 (12)	20.2 (9)	.788 (13)
Virgil	55. (17)	15. (17)	.040 (17)	.034 (17)	9.3 (15)	21.3 (12)	.572 (17)
Arithmetic Average of Grab Sample Concentrations From Flat Commercial Roofs (mg/l)							
West Allis City Hall	60. (3)	-	.029 (3)	.055 (3)	-	-	.130 (3)
Wood Veterans Hospital	128. (3)	-	.039 (3)	.012 (2)	-	-	.495 (2)

() Number of samples.

*Rooftop sampling stations Sylvester, Ewald, and Virgil are located in or adjacent to State Fair, Lincoln and Hastings drainage basins, respectively. Flat roof stations are located in or adjacent to State Fair and Wood Center basins.

TABLE V.19

ROOFTOP RUNOFF CONTAMINANT CONCENTRATIONS

Geometric Mean Event Concentration From Sloping Residential Roofs (mg/l)

Sampler Number	pH*	Soluble P	Soluble Pb	Cadmium	Total Ammonia	Nitrate plus Nitrite
Sylvester	5.9 (3)	.013 (13)	.004 (13)	.0008 (16)	1.0 (16)	1.1 (16)
Ewald	ID	.019 (11)	.004 (11)	.0005 (10)	.9 (11)	.7 (11)
Virgil	5.8 (2)	.008 (13)	.004 (14)	.0006 (15)	.8 (15)	.7 (15)

() Number of samples.
* Arithmetic Mean
ID - Insufficient Data
Rooftop sampling stations Sylvester, Ewald and Virgil are located in or adjacent to State Fair, Lincoln and Hastings drainage basins, respectively.

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TABLE V.20

COMPARISON OF RAINFALL QUALITY AND ROOFTOP RUNOFF CONTAMINANT CONCENTRATIONS

	Mean Ratio (%) of Rainfall to Event Rooftop Runoff Concentration*						
	Total Solids	Suspended Solids	Total Phosphorus	Total Lead	Sulfate	Total Ammonia-N	Nitrate plus Nitrite
Sylvester	31	44	33	13	48	80	68
Ewald	52	53	38	32	75	88	98
Virgil	47	65	53	30	69	99	71

* Including only those events for which both rainfall quality and rooftop runoff were monitored. Rooftop sampling stations Sylvester, Ewald and Virgil are located on residential roofs in or adjacent to State Fair, Lincoln, and Hastings drainage basins, respectively.

runoff concentrations. In general, rainfall quality is a significant component of rooftop runoff, increasing in importance with decreasing intensity of land use. Precipitation is the source of most of the nitrogen and sulfate to roof surfaces.

Sources of Zinc in Rooftop Runoff

To better identify the sources of zinc, the rooftop water delivery system at the Sylvester site was simultaneously sampled at three locations during three events. Rooftop water was sampled on the sloping roof surface before it entered the eaves trough sampler, in the eaves trough sampler, and in the downspout. Table V.21 shows the resulting grab sample concentrations. This analysis shows that the roof surface and the rain contribute relatively little, and identifies the galvanized steel eaves trough and downspout as major sources of zinc in rooftop runoff. The sampler, inserted in the eaves trough, was identical in cross-section and materials to the eaves trough, and although newer, shows total zinc concentrations similar to the rooftop water collected by the existing eaves troughs and downspouts.

Contribution of Rooftop Runoff to Stormwater Contaminant Concentrations

Concentrations of suspended solids, total phosphorus, total lead and total zinc in stormwater and rooftop runoff were compared for simultaneously monitored events. Table V.22 presents the mean ratio of rooftop runoff to stormwater concentration for simultaneously monitored events and for averages of all monitored data.

Suspended solids, phosphorus and lead concentrations are generally three to six times higher in stormwater than in rooftop runoff. Total zinc rooftop runoff concentrations were generally equal to or higher than the stormwater concentrations for simultaneously monitored events.

Rooftop Runoff Contaminant Loading To Stormwater

Computation of Event Loads--

Event rooftop contaminant loading to stormwater was computed for suspended solids, phosphorus, lead and zinc using contaminant concentration, rainfall depth, and the area of hydrologically connected roof surface in each drainage basin. The latter data was obtained from SEWRPC. Table V.23 presents the mean contribution of rooftop loads to stormwater loads as percent of runoff for water and percent of contaminant loads. It was necessary to use concentration data from the sloping rooftop sampler at the State Fair site in the computation of commercial and industrial roof loadings, although flat roof commercial and industrial roof runoff quality data would probably provide a better estimate if it were available.

Comparison of Rooftop Loading and Stormwater Loading--

Residential rooftops comprise a relatively small portion of the connected impervious surfaces in the mixed land use State Fair and Wood Center basins, and contribute only 5 and 6% of the stormwater volume, respectively.

TABLE V.21

COMPARISON OF EVENT TOTAL ZINC GRAB SAMPLE CONCENTRATIONS (MG/L) FROM A SLOPING ROOF SURFACE, EAVES TROUGH SAMPLER AND DOWNSPOUT

Event Date	Roof Surface	Eaves Trough Sampler	Downspout
820521	.07	.46	.52
820526	.03	.69	.64
820923	.06	1.10	.75
MEAN	.05	.75	.64

TABLE V.22

COMPARISON OF ROOFTOP RUNOFF AND STORMWATER CONTAMINANT CONCENTRATIONS

	Mean Ratio (%) of Rooftop to Stormwater Concentrations*			
	Suspended Solids	Total Phosphorus	Total Lead	Total Zinc
State Fair	33 (23)	26 (20)	24 (21)	125 (200)
Wood Center	23 (17)	31 (23)	18 (10)	112 (131)
Lincoln	17 (9)	14 (14)	19 (13)	256 (292)
Hastings	34 (21)	18 (17)	36 (38)	948 (715)

*Including only those events for which both rooftop runoff and stormwater were monitored. Roof Station Sylvester was compared with State Fair and Wood Center basins, Ewald with Lincoln, and Virgil with Hastings.

() Ratio (%) of geometric mean concentration for all monitored rooftop runoff events to flow weighted average stormwater concentration for all events monitored during the project.

TABLE V.23

MEAN CONTRIBUTION OF ROOFTOP LOADS TO STORMWATER LOADS

	Average Percent of Total Load From Residential Roofs						
	N	Average Rainfall (inches)	Runoff	Suspended Solids	Total Phosphorus	Total Lead	Total* Zinc
State Fair	9	.37	5	2	1	1	4
Wood Center	7	.46	6	2	2	1	5
Lincoln	4	.51	15	3	2	3	26
Hastings	4	.54	23	7	5	8	195**

	Average Percent of Total Load From Commercial and Industrial Roofs***					
	N	Average Rainfall (inches)	Runoff	Suspended Solids	Total Phosphorus	Total Lead
State Fair	9	.37	36	12	9	8
Wood Center	7	.46	24	6	7	4

*Number of samples for total zinc are one less than otherwise listed for each site. Zinc loads are adjusted downward by approximately 30% to allow for eaves troughs and downspouts not constructed of galvanized steel.

**Includes event where the calculated load from rooftops was larger than the calculated total stormwater load.

***Loading was computed using concentration data from the sloping roof residential samplers at the State Fair site.

Commercial and industrial roofs comprise a greater proportion of the connected imperviousness of these basins, and contribute an estimated 36 and 24% of the water load.

Residential rooftops comprise more of the connected impervious area at the predominantly high and medium density residential sites, contributing 15 to 23% of the water load at Lincoln and Hastings.

In general, the load from residential roofs of suspended solids, total phosphorus and total lead in the high density residential and commercial and industrial land use basins is overshadowed by other sources of contaminants and/or other sources of runoff water. Rooftops in the Hastings medium density residential land use basin are more important contaminant sources to stormwater, with average contributions of 7% of the suspended solids, and 5 and 8% of the total phosphorus and total lead, respectively.

Although an average of approximately 30% of stormwater volume was estimated to come from commercial and industrial roofs, the proportion of pollutant load to stormwater of the above contaminants is more in the range of 5 to 10% because of the importance of other pollutant sources associated with these land uses.

The contribution of roof load of suspended solids, phosphorus and lead to stormwater loading for individual events was compared to rainfall amount. In general, there is a negative relationship, with roof contribution decreasing as rainfall increases. Other sources of contaminants play an increasingly important role with increasing event size.

The estimation of the contribution of roof load to stormwater contaminant loading for solids, phosphorus and lead is more straightforward than for zinc. The former contaminants are associated with the impervious surface area of the roof while zinc is associated with the length of galvanized steel eaves trough and downspout. No attempt was made to quantify the relationship between roof area and length of eaves trough and downspout. However, given the uniformity of residential building design and construction, it is assumed that any relationship between roof area and eaves trough and downspout length is relatively consistent throughout each land use. Therefore, the same connected impervious data used to compute loading of the other contaminants were used in the computation of total zinc rooftop runoff loads. A SEWRPC survey of the Lincoln and Hastings basins estimated that 70 and 75% of the eaves troughs and downspouts were constructed of galvanized steel. Zinc loading estimates were adjusted downward accordingly, with an estimated 70% figure used for the commercial and residential sites.

Although residential rooftop runoff zinc concentrations generally exceed the stormwater concentration in all the monitored basins, the importance of other sources is seen in the high density residential and commercial and industrial sites. Shaheen (1975) has identified motor oil and tires as major sources of zinc in urban stormwater. These vehicle-related sources are most important in areas of high traffic volume. Commercial and industrial roof downspouts are often constructed of galvanized steel. Applying the monitored zinc concentration data from residential rooftop runoff to commercial and industrial rooftop runoff in the State Fair and Wood Center basins provides estimates of 40 and 30% of the stormwater zinc load contributed by their respective roofs. Calculated rooftop runoff zinc loads for some events at Lincoln and Hastings exceeded the monitored stormwater loads. The medium density residential site, lacking high volumes of traffic, shows greater importance of roof sources of zinc to stormwater, with most of the zinc coming from roofs.

Rooftop Runoff Management

Reduction of roof runoff water and contaminant loads to stormwater can be addressed by detaching roofs from the connected impervious stormwater drainage system, and by eliminating contaminant contributing materials, such as galvanized steel, from roof construction. Management practices to disconnect roofs from the drainage system including storing rainwater on flat roofs, routing water discharged from downspouts onto pervious areas and away from direct connections to stormsewers and impervious driveways and streets and sidewalks. Replacement of galvanized steel eaves troughs and downspouts and use of nongalvanized materials in new construction will eliminate a source of zinc to stormwater.

The greater connected impervious area associated with rooftops in established commercial and industrial land use areas will often preclude routing of roof water to pervious areas. These management practices are more easily applied, and can achieve significant stormwater and contaminant reductions in medium density residential areas.

SUMMARY AND CONCLUSIONS

1. Most of the materials found on street surfaces are in the fine to coarse sand size fractions (.125 - 1.0 mm). Lead predominates in slightly smaller sizes (.063 - .25 mm), and phosphorus is more evenly distributed among all particle sizes.

2. The impact of the heavy traffic at the commercial areas is apparent. the commercial area had levels of street dirt that were two to three times greater than the high density residential area and lead loads that were five times greater.

3. Street loads are much higher on streets in poor condition or with rough texture, than on streets in good condition or with smooth texture. On these streets, dirt accumulates in the pores, cracks and potholes, but it is not readily removed by wind, rain or street sweeping.

4. Most street dirt originates from deposition of atmospheric and traffic related contaminants and breakup of pavement surface materials. A considerable amount is washed on the streets from adjacent pervious areas and from the undersides of cars during rains.

5. Levels of street dirt are very high in the early spring. After repeated sweeping and rainfall, street loads diminish to much lower levels. There is a minimal reservoir of material on the street, which is not readily diminished by either street sweeping or rainfall. This reservoir level is site dependent, largely upon street texture and condition and traffic patterns. Throughout the summer, street loads tend to range between this minimal reservoir level, and a level that is two to three times greater than this minimum.

6. Rainfall washoff of street surface contaminants is very size selective. The very small size materials are readily washed off, while larger materials are not. Following rainfall, there were averages of 87 and 60 percent net decrease in silt size particles (less than .031 mm) at two stations, whereas there was an average net decrease of 9 percent and an average net increase of 2 percent respectively at these stations for particles larger than 4.0 mm.

7. Most of the solids and lead in urban stormwater are washed off of the streets. Most of the phosphorus, however, comes from sources other than streets.

8. Seasonal variation in atmospheric deposition related to atmospheric processes and source variability is seen for some contaminants in dry and wet deposition.

9. Contaminant concentrations in wet deposition do not vary significantly by the land uses at the monitoring sites. Dry deposition of solids, lead and COD varies with land use: highest deposition rates are found at commercial sites.

10. Rooftop runoff concentrations of solids, phosphorus, lead and COD vary with land use, with higher concentrations found from roofs near commercial sites. Galvanized steel roof water collection systems are major zinc sources.

11. The relative contribution of contaminants in precipitation and rooftop runoff to stormwater quality decreases with greater intensity of urban land use, reflecting the presence of additional pollutant sources.

CHAPTER VI.

IMPACTS OF STREET SWEEPING ON URBAN STORMWATER QUALITY

INTRODUCTION

Over the past several years numerous researchers have examined street sweeping as an urban stormwater management practice. Earlier efforts focused primarily on the ability of street sweepers to clean streets, without adequately evaluating the combined interactions of sweeper efficiency, sweeping frequency, accumulation rates, rainfall frequency, and washoff, as they collectively relate to the water quality impacts of street sweeping (APWA, 1969; AVCO Economics Systems Corp., 1970; Lager and Smith, 1974; Sartor and Boyd, 1972; Shaheen, 1975). These researchers typically reported street sweeping efficiencies of 30-70 percent, and, premised on that, advocated street sweeping as an urban stormwater management tool.

Subsequently, other researchers made more comprehensive evaluations of pollutant accumulation, sweeper removal and rainfall washoff, and their findings were less positive. Pitt (1979) in San Jose, California, found that it would take an increase of from one sweeping per month to three per week (at a ten fold increase in sweeping costs) to achieve a 25 percent reduction in stormwater loads. Terstriep et. al. (1982) found that sweeping once a week could reduce street loads, but sweeping twice a week did not reduce them further. Their analysis of the water quality impacts of street sweeping was inconclusive. Of 14 data sets of pollutant storm loads, two showed increases of more than 10 percent when the basins were swept, three showed decreases of more than 10 percent, and nine showed changes of less than 10 percent in either direction. Pitt (1983) in Bellevue, Washington, under conditions of frequent rainfall, did not find street sweeping to be an effective means of reducing stormwater pollution.

This project has evaluated the water quality effects of street sweeping through three ways: First, in situ street sweeper removal rates of street surface contaminants were examined. Secondly, stormwater in paired test and control basins, where street sweeping tests were being conducted, was monitored in an attempt to identify the water quality impacts of street sweeping. Lastly, a model has been developed to more clearly define the benefits of street sweeping under a variety of conditions. These are discussed in this chapter.

STREET SWEEPER REMOVAL OF STREET SURFACE CONTAMINANTS

As noted in Chapter V., street surface contaminant loads in the test areas were routinely monitored over the project period. Several comparisons of street surface pollutant loadings before and after street sweeping were made to evaluate sweeper removal. In many instances, when the loads on the street were low, there was more material on the street following sweeping than beforehand. Factors that could contribute to an increase in observed total loadings include 1) the physical detachment of materials that had previously adhered tightly to the pavement (and was inaccessible to presweeping sampling and perhaps rainfall washoff as well), 2) the physical disintegration of the street surface material itself, especially in areas with deteriorating streets and 3) scatter in data due to 25 percent allowable error. Within various particle sizes, there may be a net increase in fine particles due to the disintegration of coarse aggregates or organic materials. In all of the above cases, street sweeping may actually contribute to greater washoff of street surface pollutants.

At each site, street sweeping removal efficiencies vary proportionally to the levels of street surface pollutants. With decreasing street loads, efficiencies diminish to zero at some (site dependent) low level. At lower levels yet, sweeping actually adds to material on the street. Tables VI.1 and Figures VI.1-5 present the results of regressing the amounts of material removed by sweeping upon the initial load on the street. At each site, the X intercept (the street load below which sweeping has no beneficial impact) corresponds closely to the 'reservoir' level (see Chapter V.) at each site. This relates again to the relative inaccessibility of the reservoir load. It also relates to a maximum frequency of sweeping beyond which no reduction in street load is attained.

Table VI.2 presents average street sweeper removal efficiencies, based upon the sum of the loads removed by sweeping divided by the sum of the loads prior to sweeping. Overall removal efficiencies range from about 16-37 percent of total solids at the various sites. These values appear low compared to literature values, which are more typically 30-70 percent (Sartor and Boyd, 1974; Pitt, 1979). These values are low because the street loads found in this project were much lower than those found in these earlier studies (see Chapter V.) and when street loads are low, street sweeping is relatively ineffective, as noted above. At higher street loads, sweeping efficiencies are higher. At Congress and Hastings, under high street loads, sweeper removal approximates 60 percent (Figures VI.2-3).

Sweeper efficiency is lowest at State Fair, likely because of the high incidence of parked cars and the resultant inaccessibility of the curb load. Sweeper efficiency is also low at the parking lots, likely because of the diffuse nature of the contaminants there. There are few curbs against which wind blown materials can accumulate, so only the main broom of the sweeper is used. Interestingly, there is no difference between efficiencies at Rustler Rough and Rough Smooth, although their surface textures and conditions are markedly different.

Generally there is a slight increase in sweeper removal with increasing particle size. There is a significant difference in the removal of grass and leaves versus the remaining dust, dirt and gravel portions.

TABLE VI.1

STREET SWEEPER REMOVAL RATES AS A FUNCTION OF STREET SURFACE LOADS

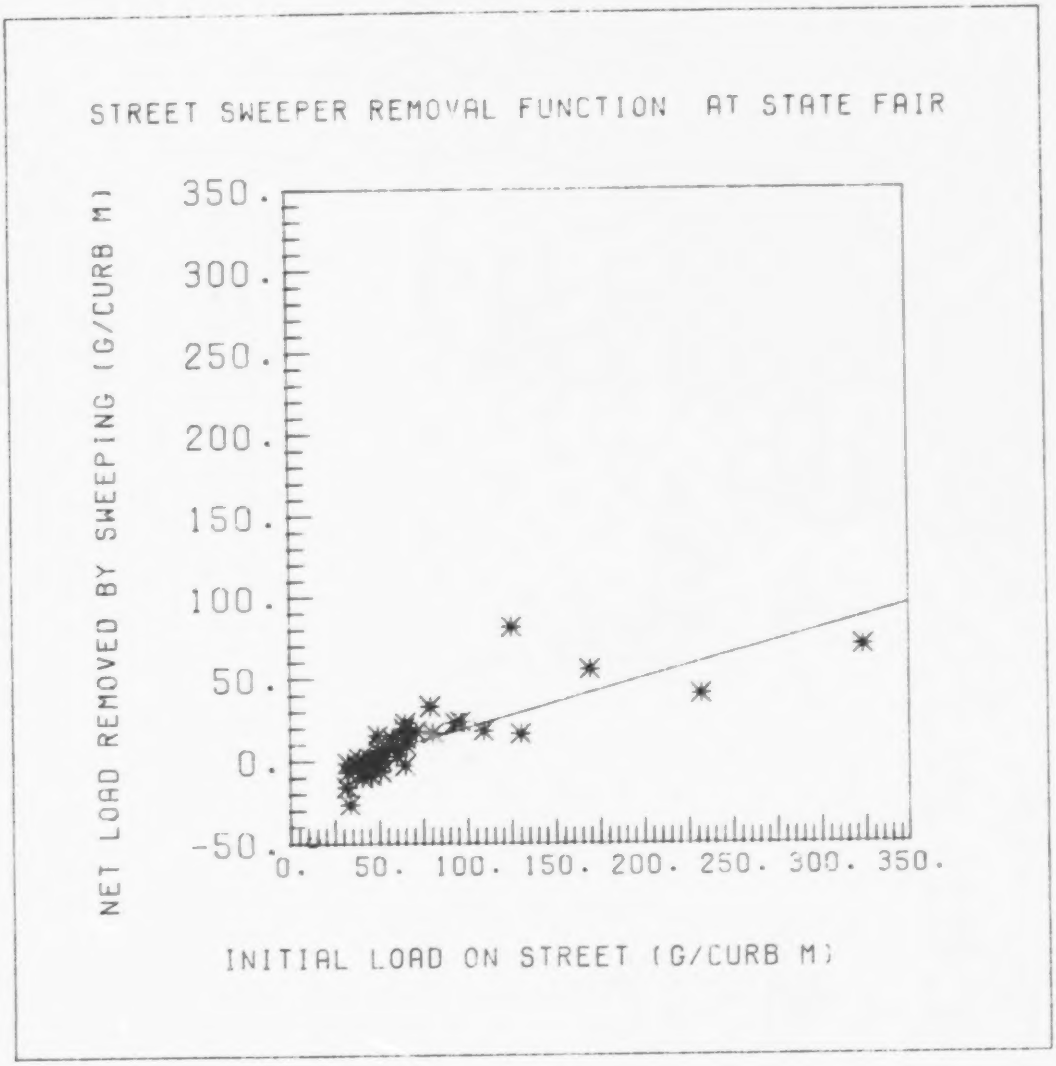
ID	Regression Statistics				Observed Street Loads***			
	N	Regression Equation*	F	X Intercept**	Min.	Q_1	Q_3	Max.
State Fair	39	.304X - 10.69	59.9	35.2	31.2	45.3	79.7	659.2
Congress	30	.621X - 8.97	241.4	14.4	11.5	19.7	36.8	119.2
Rustler Rough	9	.526X - 7.29	9.1	13.9	7.6	17.5	267.3	55.1
Rustler Smooth	11	.393X - .89	11.4	2.2	1.5	3.6	6.4	9.8
Hastings	24	.637X - 5.09	127.1	8.0	5.2	8.5	16.4	61.8

* Regression of the amounts of material removed by sweeping upn the initial street loads (x)

** X intercept is the estimated minimum street load below which street sweeping has no impact

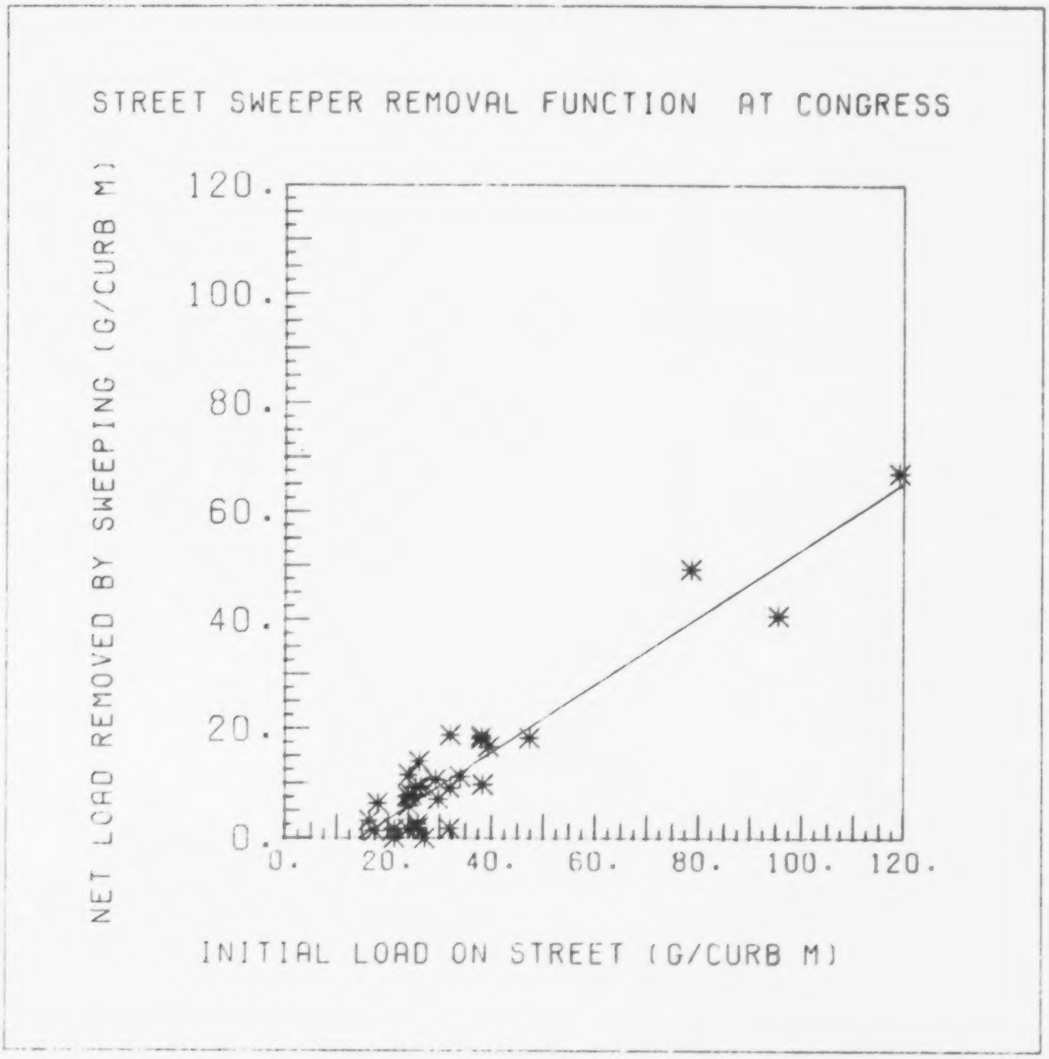
*** Loads are in g/curb m at State Fair, Congress and Hastings, and in g/m^2 at the Rustler sites. Q_1 and Q_3 are the first and third quantiles

FIGURE VI.1



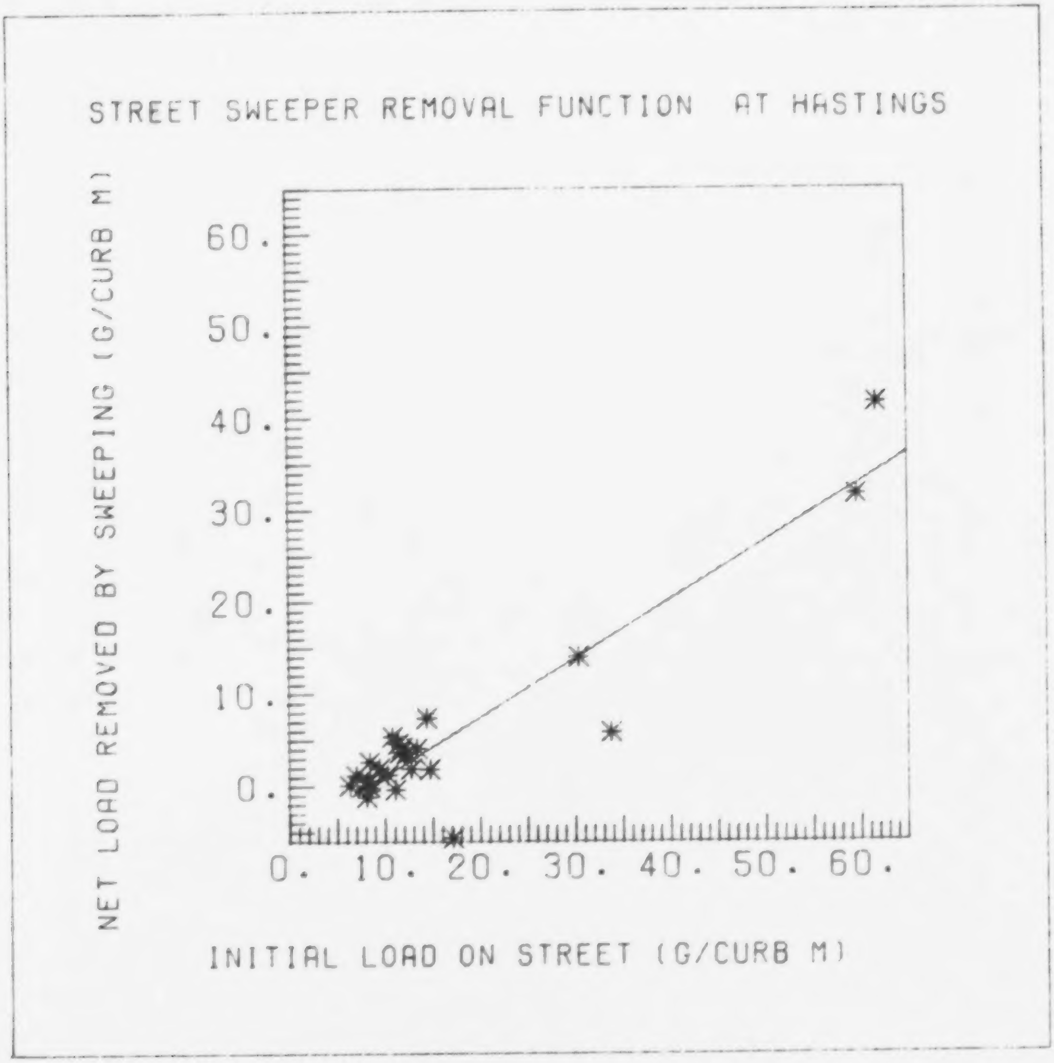
Asterisks are observed values.
Solid line is regression of load removed on initial load.

FIGURE VI.2



Asterisks are observed values.
Solid line is regression of load removed on initial load.

FIGURE VI.3



Asterisks are observed values.
Solid line is regression of load removed on initial load.

TABLE VI.2

AVERAGE STREET SWEEPER REMOVAL EFFICIENCIES*
OF TOTAL SOLIDS, BY PARTICLE SIZE

Site	N		Particle Size (mm)											
		Min	4.0	2.0	1.0	.5	.25	.125	.063	.031				
		Max		4.0	2.0	1.0	.5	.25	.125	.063	.031	Total+	Grass	Leaves	Total++
State Fair	39		16.5	17.4	15.8	16.5	14.5	13.4	13.3	12.6	12.7	15.4	33.8	57.6	15.9
Congress	30		29.1	30.5	26.6	24.8	15.9	15.6	15.2	16.1	21.6	22.3	51.4	63.1	36.6
Rustler Rough	9		28.7	29.7	24.5	17.3	16.2	18.3	21.0	22.2	11.9	20.1	68.4	52.6	20.2
Rustler Smooth	11		35.3	31.6	29.3	24.0	18.4	18.7	22.0	21.4	5.3	20.0	76.9	50.0	20.2
Hastings	24		30.3	15.9	21.0	29.9	34.9	29.7	35.2	33.7	33.6	30.3	76.3	41.4	33.3
All Streets	93		21.0	19.5	17.7	18.5	16.3	15.2	16.3	16.8	17.6	17.9	54.9	59.6	22.4
All Parking Lots	20		29.9	39.2	24.9	18.3	16.6	18.4	21.3	22.0	10.2	20.1	71.9	51.6	20.2

*Average efficiency is the sum of the net changes in street loads (before-after sweeping), divided by the sum of the street loads before sweeping, times 100. It is a weighted average percent removal.

+Total exclusive of grass and leaves.

++Total inclusive of grass and leaves.

When individual particle size loads are coupled with their respective composite concentrations, individual loads and removal rates for the various parameters can be obtained. Table VI.3 gives overall removal efficiencies for various parameters. Removal efficiencies differ from total solids due to the various concentrations of different parameters in different sizes, to the various particle size distributions at the different sites, and to the concomitant sweeper removal efficiencies for the various sizes. Overall, removal of lead is lower than of total solids, while removals of phosphorus, COD and volatile solids are higher than of total solids. The degree of difference of the latter is largely dependent on the amount of grass and leaves present at each site.

Table VI.4 gives average sweeper removal rates for total solids, total phosphorus, total lead, COD and volatile solids. These are average rates for the entire study period. Actual removal rates vary daily and seasonally, in response to daily and seasonally variable loads. Total solids and total lead removal rates are highest in the spring. Removal rates for phosphorus, COD and volatile solids vary seasonally for some land uses, depending primarily upon the extent of organic source materials. Again, the overall removal rates are relatively low, due to the low street loads observed in this project.

MONITORING THE WATER QUALITY IMPACTS OF STREET SWEEPING

A primary objective of this project has been to demonstrate the effects of street sweeping on stormwater quality. To do so, a conventional test and control experiment design was chosen. For each type of land use selected (commercial strip, parking lots, medium density residential and high density residential) two small, homogeneous, proximate watersheds were identified. Within each pair, one watershed was designated as the test site, and the other the control site. Street sweeping frequencies at the control sites were always maintained at the same frequencies that are normally maintained by the respective municipalities. These frequencies are weekly for the commercial control site (Wood Center), monthly for the residential control sites (Burbank and Lincoln) and bi-monthly for the parking lot control site (Post Office). Street sweeping frequencies at the corresponding test sites alternated every two months with control and test periods. During control periods, the test sites were swept at their respective control frequencies and on the same days that the corresponding control sites were swept. During test periods, test sites were swept more frequently. Test period sweeping frequencies were two or three times per week at the commercial test site (State Fair), weekly or twice weekly at the residential test sites (Hastings and Congress), and bi-weekly or weekly at the parking lot test site (Rustler). Whenever a control site was swept, either during a test or control period, the corresponding test site was also swept. During test periods, the test sites were swept additional times when the control sites were not swept. An evaluation of the water quality effects of street sweeping was made using events that were monitored at both the test and control paired sites. A control event was defined as an event for which the date of last sweeping was

Table VI.3

AVERAGE STREET SWEEPER REMOVAL EFFICIENCIES* OF VARIOUS PARAMETERS

Site	Total Solids	Total Phosphorus	Total Lead	COD	Volatile Solids
		Inclusive of Grass and Leaves			
State Fair	15.9	18.1	12.2	20.2	21.6
Congress	36.6	46.8	16.6	51.7	54.3
Rustler Rough	20.2	23.1	16.9	19.3	20.6
Rustler Smooth	20.2	21.2	20.5	19.1	22.6
Hastings	33.3	38.6	32.6	42.1	43.7
		Exclusive of Grass and Leaves			
State Fair	15.4	15.1	12.2	14.4	14.4
Congress	22.3	18.7	12.2	19.2	20.2
Rustler Rough	20.1	22.6	16.8	18.7	19.7
Rustler Smooth	20.0	19.5	20.5	17.2	19.9
Hastings	30.3	29.0	32.2	28.4	29.7

* Average efficiency is the sum of the net changes in street loads (before - after sweeping), divided by the sum of the street loads prior to sweeping, times 100. It is a weighted average percent removal.

Table VI.4

AVERAGE STREET SWEEPER REMOVAL RATES* OF VARIOUS PARAMETERS

Site	Total Solids	Total Phosphorus	Total Lead	COD	Volatile Solids
Inclusive of Grass and Leaves					
State Fair	11.63	3.48	19.22	1.16	.97
Congress	12.89	13.70	5.19	7.35	7.02
Rustler Rough	4.54	.93	3.19	.37	.22
Rustler Smooth	.94	.20	1.19	.09	.06
Hastings	5.58	3.45	7.24	1.42	1.27
Exclusive of Grass and Leaves					
State Fair	10.91	2.61	18.48	.68	.86
Congress	5.01	1.91	3.48	.66	.48
Rustler Rough	4.51	.90	3.19	.35	.21
Rustler Smooth	.93	.17	1.19	.08	.05
Hastings	4.34	1.49	6.97	.36	.26

Rates are in g (Total Solids, COD, or Volatile Solids) or mg (Total Phosphorus or Total Lead) per curb meter (State Fair, Congress or Hastings) or square meter (Rustler sites) per sweeping the same for both the test and control sites. A test event was defined as an event for which the test site had been swept at least one additional time since both test and control sites had last been swept together. By comparing the water quality between test and control sites and test and control events, the observed water quality impact of street sweeping was determined.

All of the sweeping was done by a private contractor, using either a three or a four wheeled mechanical broom sweeper. The respective municipalities did not swept in these areas for the duration of the study. Sweeping was postponed or cancelled if it was raining or if greater than .2 inches of rainfall had occurred within 24 hours prior to a scheduled sweeping. Because of the backwater problems at Congress, data from Congress was unusable, and a paired analysis with its counterpart (Lincoln) was not possible. This necessitated dropping this analysis from the high density residential areas.

Using this experimental design, inherent differences in stormwater quality between the paired test and control sites are manifested during control events. When differences in stormwater quality between the test and control sites during the test events are adjusted for by the differences observed during control events, the net difference was assumed to be attributable to the accelerated street sweeping. This analysis can only be conducted on those events when both the test and control sites were monitored. Unfortunately, at all paired stations for roughly half of all events, either the sampler at the test site or the control site (or sometimes both) failed to operate properly.

The experimental design assumes that reliable relationships between stormwater characteristics at the test and control sites exist under uniform or control conditions. This assumption was deemed reasonable because of the physiographic similarities of the paired sites, and their proximity to each other, thereby minimizing local rainfall differences. However, even under control conditions, there is often significant variability between test and control site stormwater concentrations. Table VI.5 presents correlation coefficients for the various paired sites and selected pollutants for control events. The correlations range from .29 to .98. The best correlations overall are found at Rustler and Post Office.

The variability in water quality between test and control sites under control conditions makes isolating the water quality effects of street sweeping difficult. Real improvements in stormwater quality could exist but be masked by the variability in the data. A large number of samples would then be required to define these improvements. Unfortunately, because of the aforementioned difficulty in obtaining paired samples, the maximum number of paired samples in either a test or control event group was 26. Most numbers were considerably smaller than this.

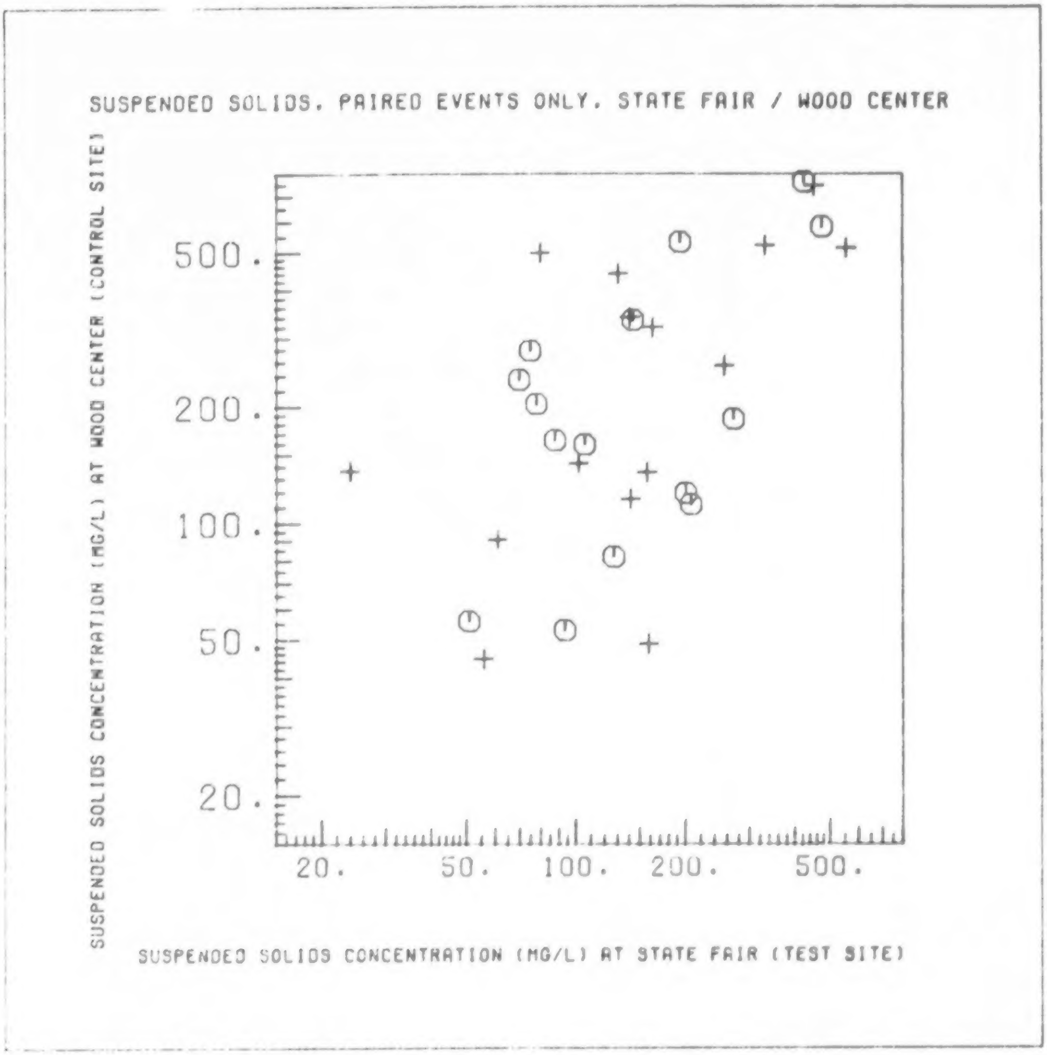
Figures VI.4-6 illustrate concentrations of suspended solids at the test and control sites for paired events. Control events are indicated on these plots by circles, and test events by crosses. The variability in both the test and

TABLE VI.5

CORRELATIONS (r) OF SELECTED PARAMETERS FOR CONTROL EVENTS

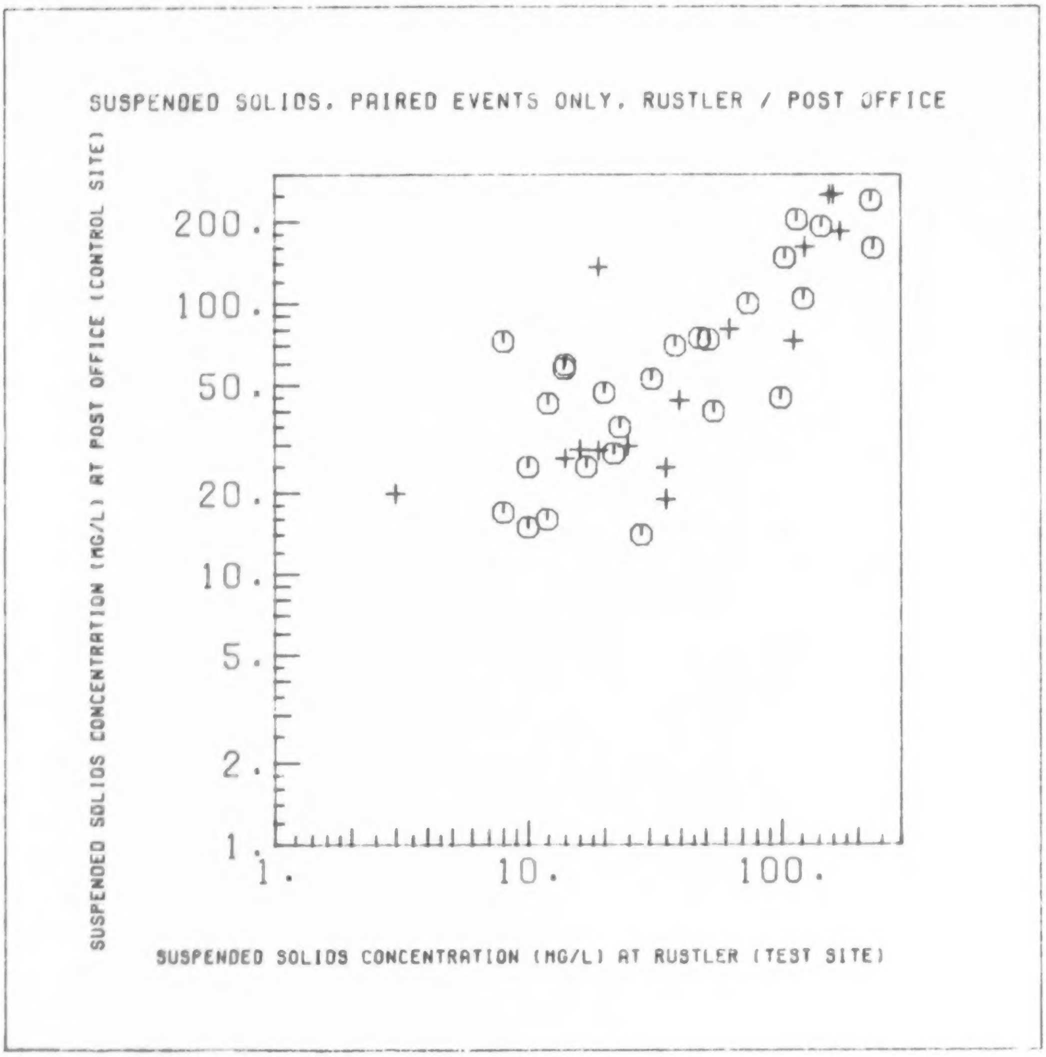
Parameter	Sites State Fair, Wood Center (Commericial)	Rustler, Post Office (Parking Lots)	Hastings, Burbank (Residential)
Suspended Solids	.74	.86	.34
Total Phosphorus	.63	.72	.58
Total Lead	.49	.79	.39
Total Zinc	.64	.70	.75
BOD	.57	.52	.98
COD	.29	.88	.96

FIGURE VI.4



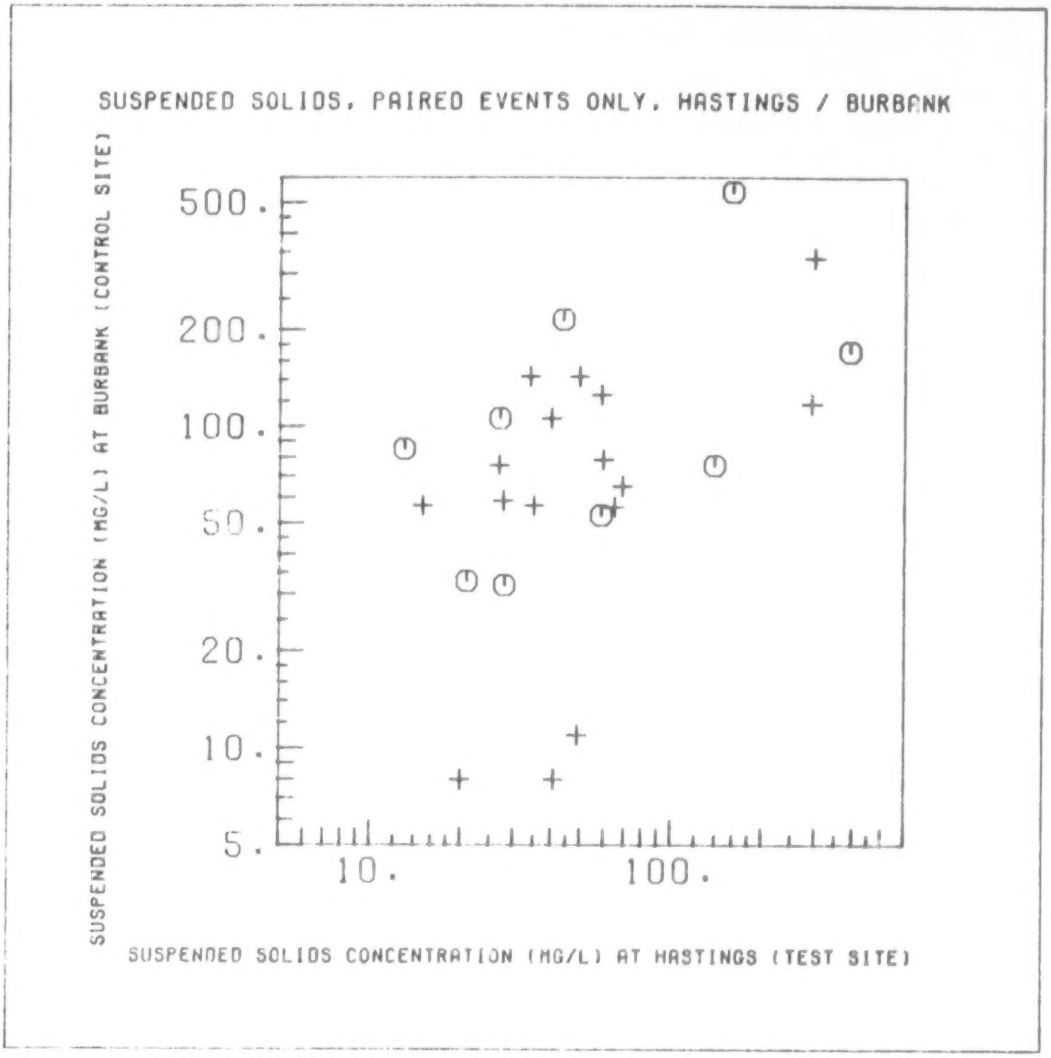
Circles are control events, crosses are test events.

FIGURE VI. 5



Circles are control events, crosses are test events.

FIGURE VI.6



Circles are control events, crosses are test events.

control event data is evident, as is the subsequent difficulty in defining the effects of street sweeping on stormwater quality. Several points can be made to assist in interpreting these plots.

Both the X and Y axes are plotted on a log scale with identical minimum and maximum values, although the scaling of the X and Y axes may appear different. A line of equal concentrations at both the test and control sites would be a 45 degree slope originating at the X-Y intercept. A well-fit line approximating a 45 degree slope would indicate that the test and control site stormwater concentrations were both equal and consistent. A well-fit line with a slope less than 45 degrees would indicate that the test site had consistently higher concentrations than the control site, and a slope of greater than 45 degrees would indicate the opposite.

If more frequent street sweeping at the test site had improved stormwater quality at the test site (relative to the control site), the slope of a line through the plotted test event concentrations would be higher than the slope of a line through the plotted control event concentrations. While that is frequently the case, often it is not. Either way, there is generally so much scatter and overlap in both the test and control event data, that it is very difficult to isolate any actual stormwater quality impacts of street sweeping.

Table VI.6 presents a statistical analysis of this data. A one-tailed Mann-Whitney test was employed to test if the median of the ratios of the test site concentration over the control site concentration for test events was less than the median of the ratios of the test site concentration over the control site concentration for control events. Because it was a one-tailed test, if the median of the test event ratios was in fact greater than the median for the control event ratios, a one-tailed test for a 'less than' condition is not possible. When the median of the test events ratios is less than the median of the control event ratios, the ratio of those two ratios indicates the relative improvement in stormwater quality. For example, if the median test event ratio was .85 and the median control event ratio was .95, the ratio of the two would be .85/.95, or .89. This would indicate that the test site had an 11 percent improvement in stormwater quality for test events relative to the control site.

The alpha statistic, or the attained level of significance, reflects the confidence one should have in the estimate of observed water quality improvements. A generous test of significance would require an alpha level of less than .1, while a value of less than .05 would be preferred for greater confidence in the estimate.

As can be seen from these tables, the median of the test event ratios is often greater than the median of the control event ratios. When in fact the median of the test event ratios is less than the median of the control event ratios, the alpha statistic is almost invariably greater than .1, and the improvement in water quality is not statistically significant. This lack of significance

TABLE VI.6

STATISTICAL ANALYSES OF THE EFFECTS OF STREET SWEEPING USING PAIRED DATA*

	Test Events		Control Events			
Parameter	N	Median Ratio**	N	Median Ratio**	T/C***	Alpha+
			State Fair/Wood Center			
Suspended Solids	16	.65	15	.66	.98	.28
Total Phosphorus	16	1.01	15	1.08	.94	.25
Total Lead	15	.54	14	.67	.81	.36
Total Zinc	5	1.14	6	.83	1.37	++
			Rustler/Post Office			
Suspended Solids	15	.77	26	.67	1.15	++
Total Phosphorus	16	.89	26	.90	.99	.23
Total Lead	16	.78	26	.68	1.15	++
Total Zinc	10	1.12	10	1.69	.66	.07
			Hastings/Burbank			
Suspended Solids	16	.69	9	.64	1.08	++
Total Phosphorus	16	.98	9	.82	1.20	++
Total Lead	15	1.00	9	.50	2.00	++
Total Zinc	8	.61	5	.87	.70	.28

* Using a one-tailed Mann-Whitney test.

** Median of the ratios of the test site concentrations over the control site concentrations.

*** T/C = test event median ratio over the control event median ratio

+ Alpha = attained level of significance. For significant differencies, alpha should be less than .1, and preferably less than .05

++ A one-tailed test of the median test event ratio being less than the median control event ratio is not possible when the former is greater than the latter.

is due to the overlap and scatter in the date. The results of these analyses do not support evidence of improvements in stormwater quality resulting from more frequent street sweeping.

These analyses are not conclusive however in that stratification by season or by some other factor could perhaps isolate a time when street sweeping does have a greater water quality impact. Or, given the large scatter in the control data, a larger number of samples might define differences that exist but cannot be isolated in the existing data base. In either case, there is not enough data to either stratify by season or to conclusively isolate a real change in water quality from the natural variability in the event mean concentrations.

MODELING THE WATER QUALITY IMPACTS OF STREET SWEEPING

The water quality monitoring undertaken in this project was unable to quantify the water quality impacts of street sweeping. Intuitively, there has to be some water quality benefits resulting from pollutant source reduction. While the in situ water quality benefits were not quantifiable, other processes were monitored in this project that allow for the mathematical modeling and estimation of those benefits.

A simplistic, stoichastic model with net daily accumulation rates, sweeper removal and street washoff functions was developed by the WDNR. It estimates street loads, sweeper removal, and washoff from streets under a variety of street sweeping programs. This model is called the Street Load and Washoff model, or SLAW. SLAW is used to estimate the street load, sweeper removal and washoff from streets under a variety of street sweeping programs.

SLAW has a number of attributes that deserve mention. First, SLAW is site specific to the project test sites, in that it uses site specific particle size distribution, street sweeper removal, and rainfall washoff rates that were measured at each of the test sites. Secondly, SLAW only considers street load, and does not consider loadings from surrounding land uses (roofs, lawns, driveways, etc.). Therefore, it estimates only washoff from streets, and any predicted improvements in water quality due to street sweeping are only applicable to that portion of the total urban runoff. Thirdly, SLAW does not estimate runoff or project water quality concentrations. Lastly, SLAW incorporates a simple net daily accumulation function, and can not be used as a pollutant source mass balance model.

SLAW incorporates three primary functions: net daily accumulation, street sweeper removal, and rainfall washoff. Net daily accumulation is a constant daily increment in street load, that is particle size dependent. It is the one variable that is used to calibrate SLAW. Accumulation rates are input in fine (less than .125 mm), medium (.125 - 2.0 mm) particle and coarse (more than 2.0 mm) sizes. These are further subdivided into the particle sizes used in this study (-.031, .063, .125, .25, .5, 1.0, 2.0, and 4.0 mm) exclusive of grass and leaves, according to the measured particle size distribution at each site. These accumulation rates are constant and do not vary by season or with other factors.

Street sweeper removal rates are site specific and are determined by the average removal rate (percent) in each particle size, adjusted for the total removal rate predicted by site specific regression equations. The values used are those listed previously in this chapter in the subchapter on street sweeper removal.

Rainfall washoff functions are also site specific. They use the average percent washoff measured for each particle size, as listed in Chapter V. Washoff removal varies with initial street load and particle size, but not with rainfall amount and intensity. All events larger than a tenth of an inch are considered to have the same impact on washoff, and events less than a tenth of an inch are considered to have no impact on washoff.

SLAW was calibrated using 1981 street load, rainfall and street sweeping data, by adjusting the fine, medium and coarse accumulation rates, to derive approximate total and individual particle size loads over the 1981 period. Subsequently, four different "years" of randomly generated rain data were developed, corresponding to the average number of events per month with greater than one tenth of an inch of rain. The four different data sets were developed because of the strong sensitivity of sweeper related impacts to rainfall frequency and timing. The results presented here are all averages of four runs of the model using the four different rainfall data sets.

The model was run for State Fair, Congress and Hastings. It was not attempted for Rustler Smooth or Rough, where the washoff data indicated a net gain in particulate loading for many of the particle sizes. And, because fall leaf drop is so variable, and the relative need for leaf control is so apparent, the modeling projections terminate at the end of September, prior to the onset of leaf fall. Because of the similarities of the output from April (after the streets are initially cleaned) through September, all of this data has been grouped together. Lastly, the output presented herein assumes that the baseline street sweeping frequencies, against which other sweeping frequencies and related water quality impacts are measured, are those which are currently being undertaken for aesthetic reasons. In other words, the baseline sweeping frequencies are NOT assumed to be no sweeping at all. The respective baseline frequencies are once per week at State Fair (commercial) and once every four weeks at Congress and Hastings (residential). The additional costs (sweeping effort) and related benefits (reduction in washoff from streets) associated with more frequent sweeping are considered to be the additional costs and benefits above and beyond those currently incurred by and achieved with present street sweeping practices for aesthetic reasons.

Tables VI.7-9 indicate the projected reductions in street washoff resulting from increased sweeping. At baseline or normal sweeping frequencies, street washoff in the first month of the sweeping season is two to four times higher than the monthly washoff over the rest of the year (exclusive of fall leaf drop). If fall leaf drop was controlled, the loading from the first month of the year would be approximately one-fifth to one-third of the total annual loading washed off of the streets.

TABLE VI.7

PROJECTED REDUCTION IN WASHOFF FROM STREETS AT STATE FAIR DUE TO INCREASED SWEEPING

	March				April - September			
		Washoff Reduction				Washoff Reduction		
Sweeping Interval (Days)	Total Washoff**	Percent	Amount*	Amount per Additional Sweeping**	Total Monthly Washoff*	Percent	Amount*	Amount per Additional Sweeping**
7	127.7	-	-	-	37.8	-	-	-
4	101.5	20.5	26.2	8.7	34.6	8.5	3.2	1.2
2	70.4	44.8	57.3	6.5	32.4	14.3	5.4	.7
1	48.9	61.7	78.8	3.8	30.7	18.8	7.1	.3

* g/curb meter/months
** g/curb meter/sweeping

TABLE VI.6

PROJECTED REDUCTION IN WASHOFF FROM STREETS AT CONGRESS DUE TO INCREASED SWEEPING

	March				April - September			
		Washoff Reduction				Washoff Reduction		
Sweeping Interval (Days)	Total Washoff**	Percent	Amount*	Amount per Additional Sweeping**	Total Monthly Washoff*	Percent	Amount*	Amount per Additional Sweeping**
28	56.3	-	-	-	27.5	-	-	-
14	50.1	11.0	6.2	6.2	25.0	9.0	2.5	2.5
7	40.0	28.9	16.3	5.9	22.6	17.7	4.9	1.9
4	33.3	40.8	23.0	4.0	21.1	23.2	6.4	1.3
2	27.5	51.2	28.8	2.5	19.8	28.0	7.7	.7

* g/curb meter/month
** g/curb meter/sweeping

TABLE VI.9

PROJECTED REDUCTION IN WASHOFF FROM STREETS AT HASTINGS DUE TO INCREASED SWEEPING

	March				April - September			
		Washoff Reduction				Washoff Reduction		
Sweeping Interval (Days)	Total Washoff**	Percent	Amount*	Amount per Additional Sweeping**	Total Monthly Washoff*	Percent	Amount*	Amount per Additional Sweeping**
28	40.8	-	-	-	20.1	-	-	-
14	34.7	14.9	6.1	6.1	19.7	2.0	.4	.4
7	27.6	32.3	13.2	4.8	18.6	7.1	1.5	.6
4	23.3	42.8	17.5	3.0	18.0	10.3	2.1	.4
2	20.0	51.0	20.8	1.8	17.4	13.4	2.7	.3

* g/curb meter/months
** g/curb meter/sweeping

Sweeping has its greatest impacts early in the year, when street loads are highest. In the first month of the year, highly accelerated street sweeping (every other day in residential areas and daily in commercial areas) can reduce street washoff by half. However, because street sweeping at low loads has little or no effect, once the initial spring street loads are reduced, very intensive street sweeping has considerably less effect on street loads or on washoff from streets. Highly accelerated street sweeping during the remainder of the year will reduce street washoff by only 10-30 percent. At all times of the year, the return on the effort (reduction in washoff per additional sweeping) diminishes at increasing sweeping frequencies.

Sweeping is most effective at the onset of the spring sweeping season. The data presented in Tables VI.7-9 assume a constant sweeping frequency spread evenly over each month (except when sweeping conflicts with rainfall). If however, an area was swept repeatedly until it was "clean" prior to any spring rains, would that improve the effectiveness of early sweeping? Additional runs of the model were made, this time initially sweeping each area repeatedly until it was "clean", prior to the onset of March (Table VI.10). Street loads began at their stated spring highs (350, 90, and 45 grams/curb meter for State Fair, Congress and Hastings respectively), and each area was swept repeatedly until the street loads were reduced to below the average summertime loads (50, 25, and 10 grams/curb meter respectively). By sweeping a number of times initially, and then continuing at baseline or normal sweeping frequency, the washoff in March could likewise be reduced by half but with an amount removed per sweeping that is three to four times higher than that achieved by very intensive sweeping throughout March.

Another approach to maximizing the water quality impacts of street sweeping would be to improve street sweeping efficiency. This could be accomplished by 1) restricting parking to improve curb access, 2) better operator training, 3) improved maintenance on existing equipment, and 4) improved technologies in developing new sweeping equipment.

In the study areas, parked cars were a problem only at the two commercial sites, even between 4:00 and 6:00 A.M., the usual sweeping time. Further, the primary sweeper operators had had many years of experience, were well versed in the nature and objectives of this study, and operated the equipment according to stated optimum criteria. Likewise, the brooms were replaced before significant wear developed. Pitt (1979) found that imposing parking controls on streets that were otherwise 80 percent occupied by cars would improve total solids removal from 35 to 50 percent. Otherwise, with the exception of parking controls at the commercial sites, it is somewhat doubtful that the sweeper efficiencies observed in the study could be significantly improved upon without a significant improvement in new equipment. But if such improvements were possible, what impact would the have on water quality? Total solids removal by sweeping was determined by regression equations such as the following one derived for Hastings: sweeper removal = (initial street load x .637) - 5.09 (all units are in grams per curb meter). Because the

Table VI.10

PROJECTED REDUCTION IN WASHOFF DURING MARCH WITH INTENSIVE INITIAL SWEEPING FOLLOWED BY NORMAL SWEEPING

				Washoff Reduction		
Site	Total Washoff Without Initial Cleaning* (g/curb m)	Number of Sweepings Required**	Total Washoff Following Initial Cleaning (g/curb m)	%	Amount (g/curb m)	Amount Per Additional Sweeping
State Fair	127.7	9	43.3	66	84.4	9.4
Congress	56.3	3	31.2	45	25.1	8.4
Hastings	40.8	3	20.3	50	20.5	6.8

* Based on normal sweeping intervals of 7, 28 and 28 days for State Fair, Congress and Hastings respectively.

** Number of sweepings required to clean from initial spring loads (350, 90, and 45 g/curb m respectively) to average summertime loads (50, 25 and 10 g/curb in respectively) constant (-5.09) is not zero, the removal rate (percent) is not constant, but rather increases with increasing street load. Further, there is a low level street load below which street sweeping is ineffective. In this example, sweeping will not remove material when the initial street load is below 7.99 grams per curb meter (5.09/.637). This is consistent with the idea of a reservoir expressed in Chapter V. Further, because the slope (.637) is less than 1.0, only a fraction of material above the reservoir will be removed. If however, street sweeping could be improved to lower the reservoir and remove more of the excess material above the reservoir, what effect would this have on street load, washoff and water quality? To address this question, the regression equations determining total sweeper removal were modified by halving the constant term (here now -2.545 instead of -5.09) and incrementing the slope by half of the difference between it and 1.0 (here now .8185 instead of .637). These modifications make the relative improvements in efficiency much greater at low street loads than at high street loads. The raw data, with superimposed original and revised regression lines, are presented in Figures VI.7-9.

Results of the evaluation of improved sweeper efficiency are presented in Tables VI.11-13. At Hastings and Congress, the improved efficiencies resulted in washoff reductions of roughly 10-40 percent, depending upon sweeping frequency. The more frequent the sweeping, the lower the initial street loads, the more dramatic the improvements in efficiency, and the greater the water quality impacts. At State Fair, where sweeping is more frequent and the improvements in sweeper efficiency are much more dramatic, the reduction in washoff ranged from 40 to 65 percent.

SUMMARY AND CONCLUSIONS

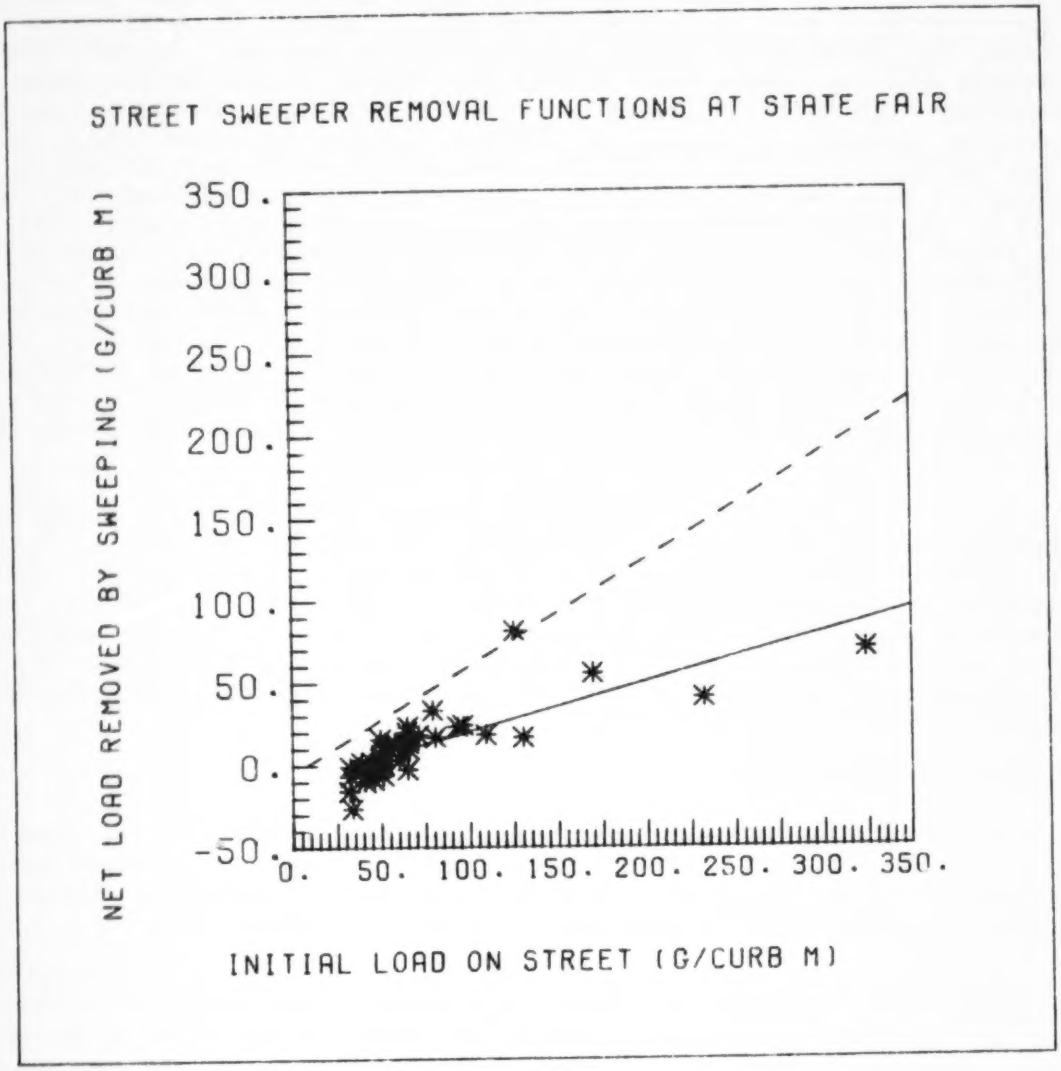
1. The variability in urban runoff, and the sampling difficulties associated with it, make it impractical to detect small improvements in water quality. This project, even with its intensive water quality monitoring efforts, was unable to substantiate the water quality benefits of street sweeping.

2. Street sweeping very early in the season is most cost effective in reducing urban stormwater pollution. Approximately one-fifth to one-third of the total annual washoff from streets may occur in the first month of the year. Repeated sweeping at the onset of the sweeping season may reduce street washoff in the first month by half, with a minimal number of additional sweepings required.

3. Once the accumulated winter street loads are reduced to "clean" levels, accelerated street sweeping is not a very effective means of further reducing street surface contaminants and urban stormwater pollution.

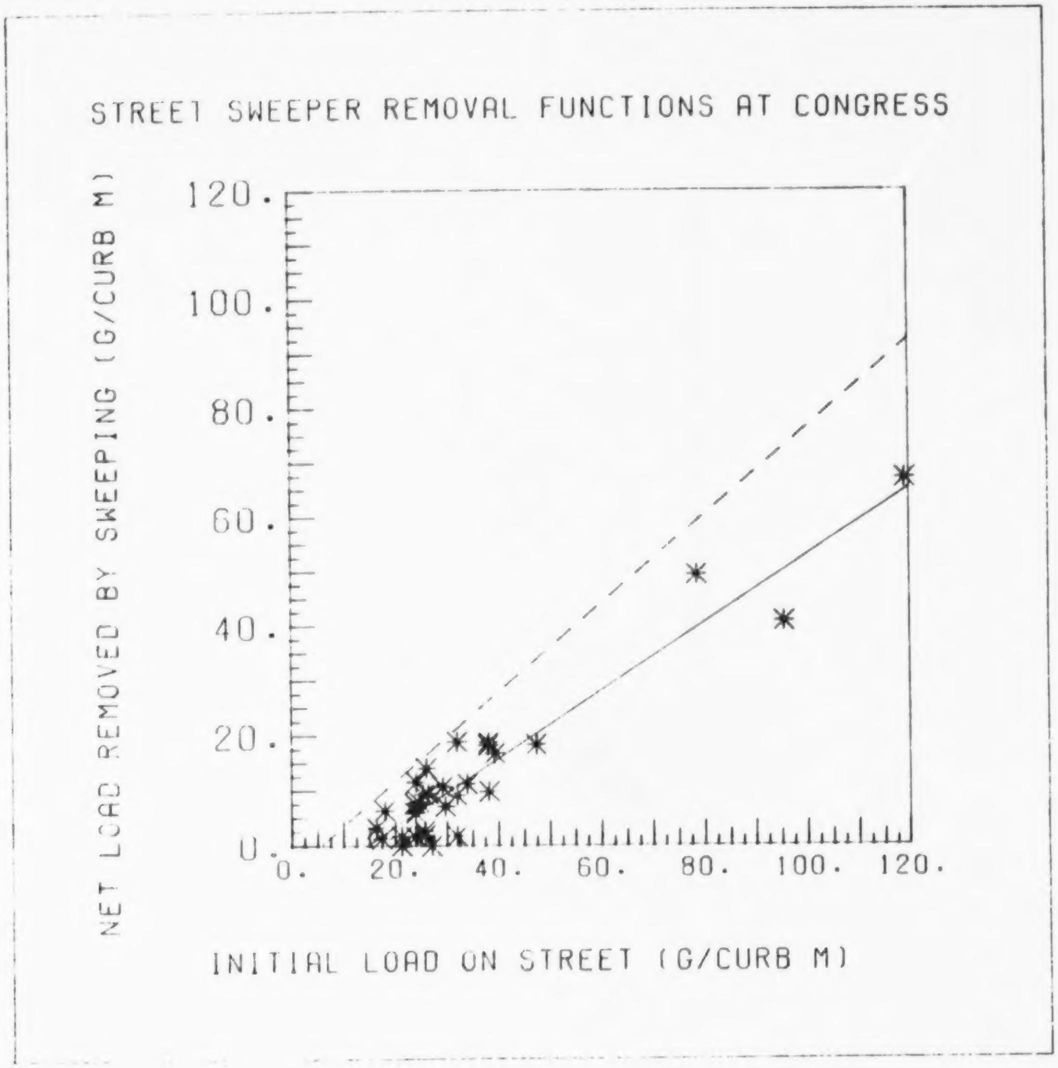
4. Significant improvements in street sweeper performance would have only small to moderate impacts on street washoff at typical (aesthetically motivated) sweeping frequencies. At more intensive frequencies, such improvements could have more significant impacts.

FIGURE VI.7



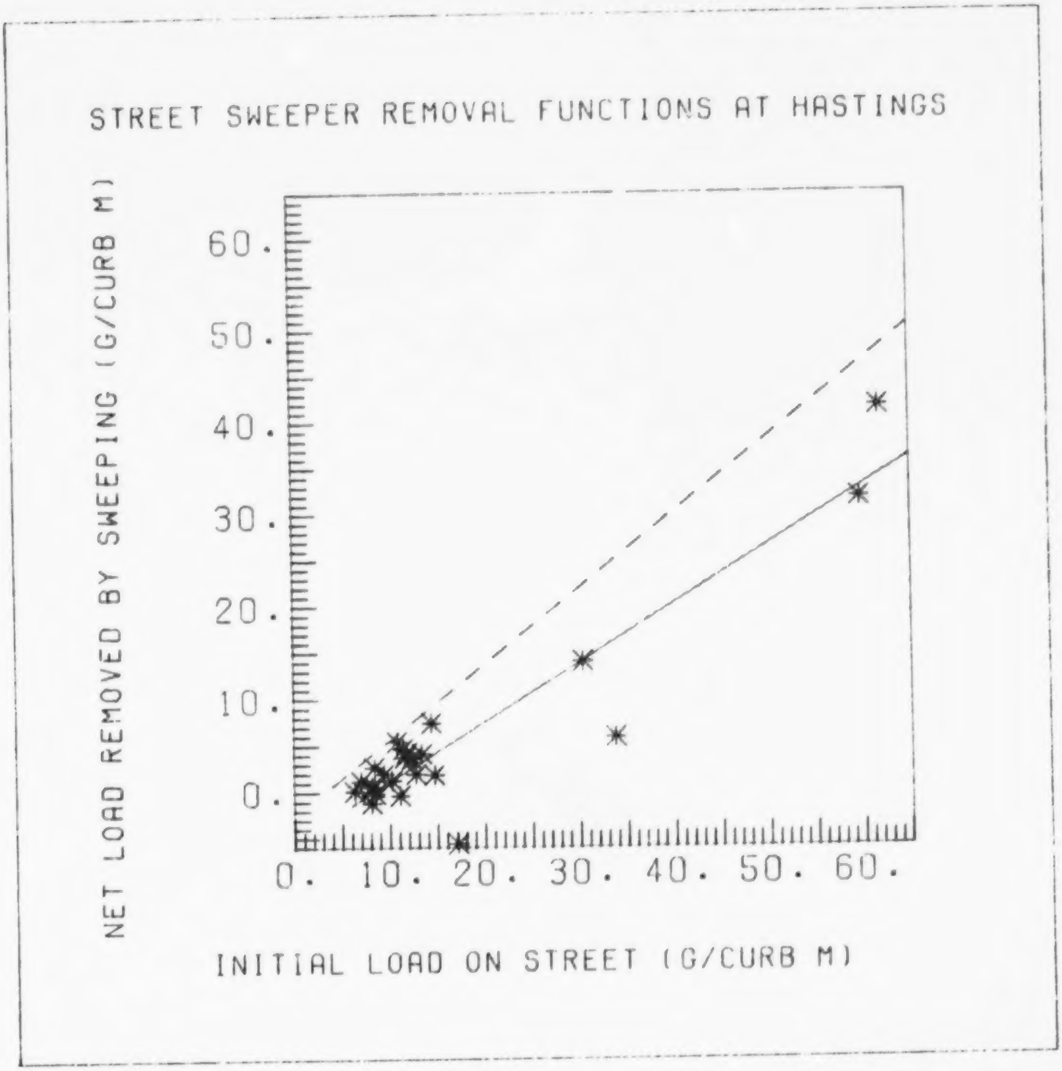
Asterisks are observed values.
Solid line is regression of load removed on initial load.
Broken line represents hypothetical improved sweeper efficiency.

FIGURE VI.8



Asterisks are observed values.
Solid line is regression of load removed on initial load.
Broken line represents hypothetical improved sweeper efficiency.

FIGURE VI.9



Asterisks are observed values.
Solid line is regression of load removed on initial load.
Broken line represents hypothetical improved sweeper efficiency.

TABLE VI.11

PROJECTED REDUCTION IN WASHOFF+ DUE TO IMPROVED STREET SWEEPER EFFICIENCY, AT HASTINGS

Sweeping Interval (Days)	March Total Washoff, Existing Efficiency*	March Total Washoff, Improved Efficiency**	March Percent Reduction	April - September Monthly Washoff, Existing Efficiency*	April - September Monthly Washoff, Improved Efficiency**	April - September Percent Reduction
28	40.8	35.9	12	20.1	17.3	14
14	34.7	27.3	21	19.7	15.3	22
7	27.6	17.4	37	18.6	12.9	31
4	23.3	14.4	38	18.0	11.5	36
2	20.0	12.6	37	17.4	10.4	40

+ All units of washoff are in g/curb m
* Amount removed = .637 (street load) - 5.09
** Amount removed = .8185 (street load) - 2.545

TABLE VI.12

PROJECTED REDUCTION IN WASHOFF$^+$ DUE TO IMPROVED STREET SWEEPER EFFICIENCY, AT CONGRESS

Sweeping Interval (Days)	March Total Washoff, Existing Efficiency*	March Total Washoff, Improved Efficiency**	March Percent Reduction	April - September Monthly Washoff, Existing Efficiency*	April - September Monthly Washoff, Improved Efficiency**	April - September Percent Reduction
28	56.3	50.6	10	27.5	24.4	11
14	50.1	41.6	17	25.0	20.3	19
7	40.0	28.2	30	22.6	16.4	27
4	33.3	21.8	35	21.1	14.1	33
2	27.5	16.8	39	19.8	12.1	39

+ All units of washoff are in g/curb m
* Amount removed = .621 (street load) - 8.97
** Amount removed = .8185 (street load) - 4.485

TABLE VI.13

PROJECTED REDUCTION IN WASHOFF+ DUE TO IMPROVED STREET SWEEPER EFFICIENCY, AT STATE FAIR

	March			April - September		
Sweeping Interval (Days)	Total Washoff, Existing Efficiency*	Total Washoff, Improved Efficiency**	Percent Reduction	Monthly Washoff, Existing Efficiency*	Monthly Washoff, Improved Efficiency**	Percent Reduction
7	127.7	65.9	48	37.8	22.7	40
4	101.5	47.6	53	34.6	19.3	44
2	70.4	312.3	55	32.4	13.5	58
1	48.9	17.3	65	30.7	13.0	58

+ All units of washoff are in g/curb m
* Amount removed = .30 (street load) - 10.2
** Amount removed = .6506 (street load) - 5.1

REFERENCES

Alley, W.M., and Smith, P.E., 1982, Distributed Routing Rainfall-Runoff Model--Version II. U.S. Geol. Survey Open-File Report 82-344, 201 pp.

Andren, A.W. and T.R. Stolzenburg. Atmospheric Deposition of Lead and Phosphorus on the Menomonee River Watershed - Volume 8. The IJC Menomonee River Watershed Study. EPA-905/4-79-029-H. U.S. Environmental Protection Agency, Chicago, Illinois. 1979. 98 pp.

American Public Works Association. Water Pollution Aspects of Urban Runoff. WP-20-15. 1969. 272 pp.

AVCO Economic Systems Corporation. Stormwater Pollution from Urban Land Activity. Washington, D.C. 1970.

Bannerman, R., J. Konrad, D. Becker, G. Simsiman, G. Chesters, J. Goodrich - Mahoney and B. Abrams. Surface Water Monitoring Data - Volume 3. The IJC Menomonee River Watershed Study. EPA-905/4-79-029-C. U.S. Environmental Protection Agency, Chicago, Illinois. 1979.

Bannerman, R. T., Michael F. Bohn, John Konrad. Surface Water Quality From To 1979 - Volume 12. Menomonee River Pilot Watershed Study. In press. 1982.

Barkdoll, M.P., D.E. Overton and R.P. Betson. Some Effects of Dustfall on Urban Stormwater Quality. Journal WPCF 49: 1976-1984. 1977.

Betson, R.P. Bulk Precipitation and Streamflow Quality Relationship in an Urban Area. Water Resources Res., 14: 1165-1169. 1978.

Characklis, W.G., C.H. Ward, J.M. King, and F.L. Roe. Rainfall Quality Land Use and Runoff Quality. J. Env. Eng. Div., Proc. ASCE, 105: 416-421. 1979.

Climatological Data for Wisconsin, National Oceanic and Atmospheric Administration, Asheville, North Caroline January 1980 - December 1982.

Colston, N.V. Characterization and Treatment of Urban Land Runoff. EPA-670/2-74-096. U.S. Environmental Protection Agency, Cincinnati, Ohio. 1974. 158 pp.

Dong, A. Dispersibility of Soils and Elemental Composition of Soils, Sediments and Dust and Dirt from the Menomonee River Watershed - Volume 6. The IJC Menomonee River Watershed Study. EPA-905/479-029-F, U.S. Environmental Protection Agency, Chicago, IL. 1979.

Doyle, W.H., Jr., and Lorens, J.A., 1982, Data Management Sysem for Urban Hydrology Studies Program. U.S. Geol. Survey Open-File Report 82-442, 271 pp.

Doyle, W.H., Jr., and Miller, J.E., 1980, Calibration of a Distributed Routing Rainfall-Runoff Model at Four Urban Sites Near Miami, Florida. U.S. Geol. Survey Water-Resources Investigations 80-1, 87pp.

Field, S. J., R. A. Lidwin. Water Assessment of Steiner Branch Basin, Lafayette County, Wisconsin. U.S. Geological Survey, Water Resources Investigation 81-52. 1982.

Field, S. J., J. Bachhuber. Hydology and Water Quality of the Galena River Basin, Wisconsin -- An assessment of Nonpoint Source Discharges. U.S. Geological Survey, Water Resources Investigation - in press.

Fugitive Dust Emissions: Their Sources and Control in Milwaukee's Menomonee River Valley. City of Milwaukee, Department of City Development. 1981.

Goettle, A. Atmospheric Contamination Fallout and their Effects on Stormwater Quality. Prog. Water Technol., 10:455-467. 1978.

Hicks, B.B., M.L. Wesley and J.L. Durham. Critique of Methods to Measure Dry Deposition. Argonne National Laboratory. EPA-600/9-80-050, U.S. Environmental Protection Agency. 1980.

Huff, F.A. Relation Between Atmospheric Pollution, Precipitation, and Streamwater Quality Near a Large Urban-Industrial Complex. Water Res., 10:945-953. 1976.

Lager, J.A. and W.G. Smith. Urban Stormwater Management and Technology: An Assessment. EPA-670/2-74-040. U.S. Environmental Protection Agency, Cincinnati, Ohio. 1974. 416 pp.

Lamorau, W., 1962, Modern Evaporation Formulas Adapted to Computer Use. Monthly Weather Review, pp. 26-28.

Novotny, V. and G. Chesters. Handbook of Nonpoint Pollution. Van Nostrand Reinhold Co., New York, New York. 1981. 555 pp.

McElroy, F.T.R., and J.M. Bell. Stormwater Runoff Quality for Urban and Semi-Urban/Rural Watersheds. Tech. Report No. 43. Purdue University, Water Resources Research Center, West Lafayette, Indiana. 156 pp.

Pitt, R. Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices. EPA-600/2-79-161. U.S. Environmental Protection Agency. Cincinnati, Ohio. 1979. 270 pp.

Pitt, R. Characterization, Sources and Control of Urban Runoff by Street Cleaning and Sewerage Cleaning in Bellevue, Washington. Draft Final Report for U.S. Environmental Protection Agency, Edison, New Jersey. 1983.

Pitt, R. and Martin Bozeman. Sources of Urban Runoff Pollution and Its Effects on an Urban Creek. EPA-600/S2-82-090. U.S. Environmental Protection Agency, Environmental Research Laboratory, Cincinnati, Ohio. 1982.

Pope, W. Impact of Man in Catchments (ii) Roads and Urbanization In: Water Quality and Catchment Ecosystems. A.M. Gower, ed. John Wiley and Sons, Chichester, England. 1980. pp. 73-112.

Rossano, A.T., Jr., et. al. Dustfall as a Source of Water Quality Impairment. Jour. San. Eng. Div., Amer. Soc. Civil Eng., 92, SA1. 1966.

Sartor, J.D. and G.B. Boyd. Water Pollution Aspects of Street Surface Contaminants. EPA-R2-72-081. U.S. Environmental Protection Agency, Washington D.C. 1972. 237 pp.

Shaheen, D.G. Contributions of Urban Roadway Usage to Water Pollution. EPA-600/2-75-004. U.S. Environmental Protection Agency, Washington, D.C. 1975.

Sheffy, T.B., et. al. First Annual Report on the Wisconsin Acid Deposition Research Program, prepared by: The Joint Acid Deposition Technical Review Committee, Madison, WI. 1983.

Solomon, R.L., J.W. Hartford, J.L. Hudson, D. Meaderhouser and J.J. Stukel. Spatial Variation of Airborne Lead Concentration in an Urban Area. J. Air Poll. Control Assoc. 27:1095. 1977.

Southeastern Wisconsin Regional Planning Commission. Inventory Findings and Forecasts - Volume 1. A Comprehensive Plan for the Menomonee River Watershed. Planning Report Number 26. 1976.

Stern, A.C., ed. Air Pollution, Third Edition, Volume I. Academic Press, New York, New York. 1976. 700 pp.

TerHaar, G.L., R.B. Holtzman and H.F. Lucas, Jr. "Lead and Lead-210 in Rainwater". Nature, 216:253. 1967.

Terstriep, M.L., G.M. Bender, and D.C. Noel. Nationwide Urban Runoff Project, Champaign, Illinois. Evaluation of Effectiveness of Street Sweeping in the Control of Urban Storm Runoff Pollution. Illinois Environmental Protection Agency. Springfield, Illinois. 1982.

Walesh, S.G., F. Scarpace, J. Goodrich-Mahoney and R. Bannerman. Land Use, Population and Physical Characteristics of the Menomonee River Watershed - Volume 2. The IJC Menomonee River Watershed Study. EPA-905/4-79-029-B. U.S. Environmental Protection Agency, Chicago, Illinois. 1979.

Walling, D.E. Water in the Catchment Ecosystem In: Water Quality in Catchment Ecosystems. A.M. Gower, ed. John Wiley and Sons, Chichester, England. 1980. pp. 1-48.

Water Resources Data for Wisconsin, U.S. Geological Survey Water Data Report WI-75-1. 1975.

Water Resources Data for Wisconsin, U.S. Geological Survey Water Data Report WI-76-1. 1976.

Water Resources Data for Wisconsin, U.S. Geological Survey Water Data Report WI-77-1. 1977.

Water Resources Data for Wisconsin, U.S. Geological Survey Water Data Report WI-80-1. 1980.